

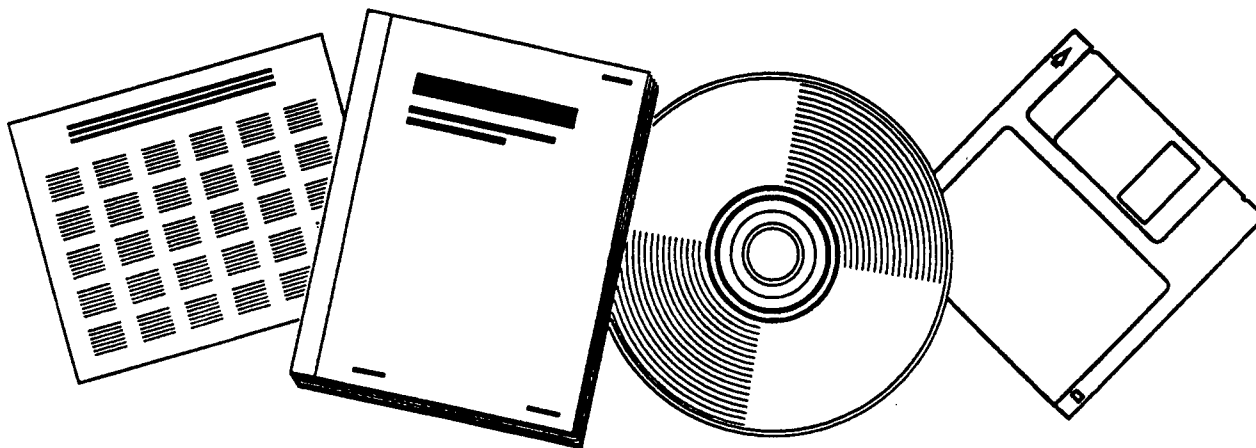


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APPENDIX C. CURRENT AND ADVANCED TECHNOLOGIES FOR THE SHIP BREAKING/RECYCLING INDUSTRY

JUL 97



U.S. DEPARTMENT OF COMMERCE
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APPENDIX C

CURRENT AND ADVANCED TECHNOLOGIES FOR THE SHIP BREAKING/RECYCLING INDUSTRY

Report No. MA-ENV-820-96003-C

Contract No. DTMA91-93-C-00004



**U.S. Department
of Transportation**


**Maritime
Administration**

JULY 1997

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Appendix C

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Technologies for the
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of Transportation

**Maritime
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EXECUTIVE SUMMARY

The domestic ship breaking/recycling industry is presently small with a few recyclers relying on hulls of former U.S. Navy warships to stay in business. On average, 55,000 tons of these ships are scrapped yearly at a few sites along the nation's coasts, using simple cutting torches and metal shears. Navy ships represent a small part of the 80 million ton per year national scrap steel recycling industry. While an additional 360,000 tons per year of U.S.-flagged commercial ships are scrapped each year, until recently all have been exported overseas, where scrap prices are higher, ship recyclers are unburdened by strong environmental regulation, and labor is inexpensive.

The practice of exporting U.S. ships for recycling has changed, however. Prohibited levels of polychlorinated biphenyls (PCBs) in plastic and rubber materials have been found in Navy and Maritime Administration ships (References 4 and 5), and it is likely that PCBs are present in all U.S. ships. The U.S. Environmental Protection Agency (EPA) has already banned the export of Navy and Maritime Administration ships for recycling, in keeping with the U.S. prohibition on export of PCBs (Reference 3), and may soon do so for all U.S. ships. This forces more ships to be recycled here, but the PCBs and other hazardous materials will further add to the cost of recycling, seriously affecting the profits of the industry (Reference 6).

Foreign nations are not silent on the question of environmental problems with old ships. Recently, the Indian Government has expressed concerns with hazardous materials in old ships that are being brought in for recycling. International attention to the problems of trade in hazardous materials continues to grow, as evidenced by the ratification by 93 nations (the United States is not among them) of the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal, which places strong restrictions on the practice (Reference 2).

In this light, this report summarizes the technology presently employed in the domestic ship breaking/recycling industry, reviews examples of new and developmental technologies for their potential to help the industry, and presents a notional idea of a fully modern domestic ship breaking/recycling yard that employs appropriate current and new technologies to recycle ships while properly handling the wastes. The yard would incorporate large, modern shears, conveyors to move metal, shredders and separators, modern hand-held cutting tools, modern waste processing facilities, integrated market planning, and most important, a single set of environmental rules and regulations that put forth a cohesive and effective, but not excessive, environmental control, monitoring, and reporting scheme.

To select the appropriate technologies and develop the needed regulatory scheme, it is recommended that a demonstration project be established. The technologies and the regulatory approaches that prove successful in this demonstration project could be made available for utilization by the metal recycling industry. This could influence the technological and regulatory development of other industries as well.

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1.0 INTRODUCTION

This and the other reports in this series (References 1, 2, 3, 4, 5, 6, and 7) provide technical, environmental, and cost/benefit evaluation of ship breaking/recycling technologies in the United States. The purpose of the project is to provide to the U.S. Department of Transportation Maritime Administration (MARAD):

- A survey of environmental problems encountered when breaking typical MARAD vessels, accomplished through appropriate testing and analysis of candidate ships;
- A survey of currently available and advanced technologies for effective removal, handling, and disposal of hazardous materials resulting from ship breaking/recycling;
- A survey of current federal, state and local environmental laws and regulations applicable to ship breaking/recycling;
- A baseline economic case for cost-effective ship breaking/recycling in the United States; and
- An environmental assessment for government ship breaking/recycling in the United States that satisfies the National Environmental Policy Act (NEPA).

This report addresses the second of these items, describing current technologies used for recycling ships in the United States and in some foreign countries, and describing and evaluating available new and advanced technologies which might be employed to improve the domestic ship breaking/recycling process.

Information in this report was gathered from interviews with persons in 11 U.S. firms involved in metals recycling, including several who are or were ship recyclers. The three most active firms were visited. Additional information was obtained and reviewed from over 30 product development organizations and manufacturers engaged in the development of innovative technologies that may have application to ship breaking/recycling. Appendix 1 contains a list of organizations and manufacturers that were interviewed or visited, and whose literature was reviewed.

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2.0 BACKGROUND

2.1 THE RECYCLING PROCESS

Ship breaking/recycling (also called shipbreaking or ship scrapping) produces several grades and types of scrap metal, some reusable components such as galley equipment and diesel engines, and, on occasion, artifacts such as portholes for the consumer market. The process can be thought of as having three distinct elements: the recovery of materials, the sale of materials, and waste management.

2.1.1 Recovery of Materials

The recovery of materials, i.e., cutting the ship apart, can be done with the ship either afloat or in a drydock. Drydocks, which are expensive and more profitably engaged in ship construction or repair, are not used unless necessary. Surface ships are often recycled afloat, since much of the ship's structure is well above the waterline and the hulk can be kept afloat as the work proceeds.

Recycling afloat begins with removal of fuel and other liquids and the removal of the ship's propeller(s) (to make it easier to pull the hulk ashore as scrapping proceeds). The interior of the ship is stripped of small articles that will fit through hatches. The uppermost decks (the superstructure) and systems are cut off first, using cutting torches, saws and shears (discussed in Chapter 3), followed by the main and lower decks. Large, reusable components are removed as they are made accessible. As the weight of the structure and machinery is removed, the remaining hulk floats higher and higher until nothing but the lowest regions of the hull remain afloat. This is then pulled ashore and cut up. Figure 1 illustrates the recycling process.

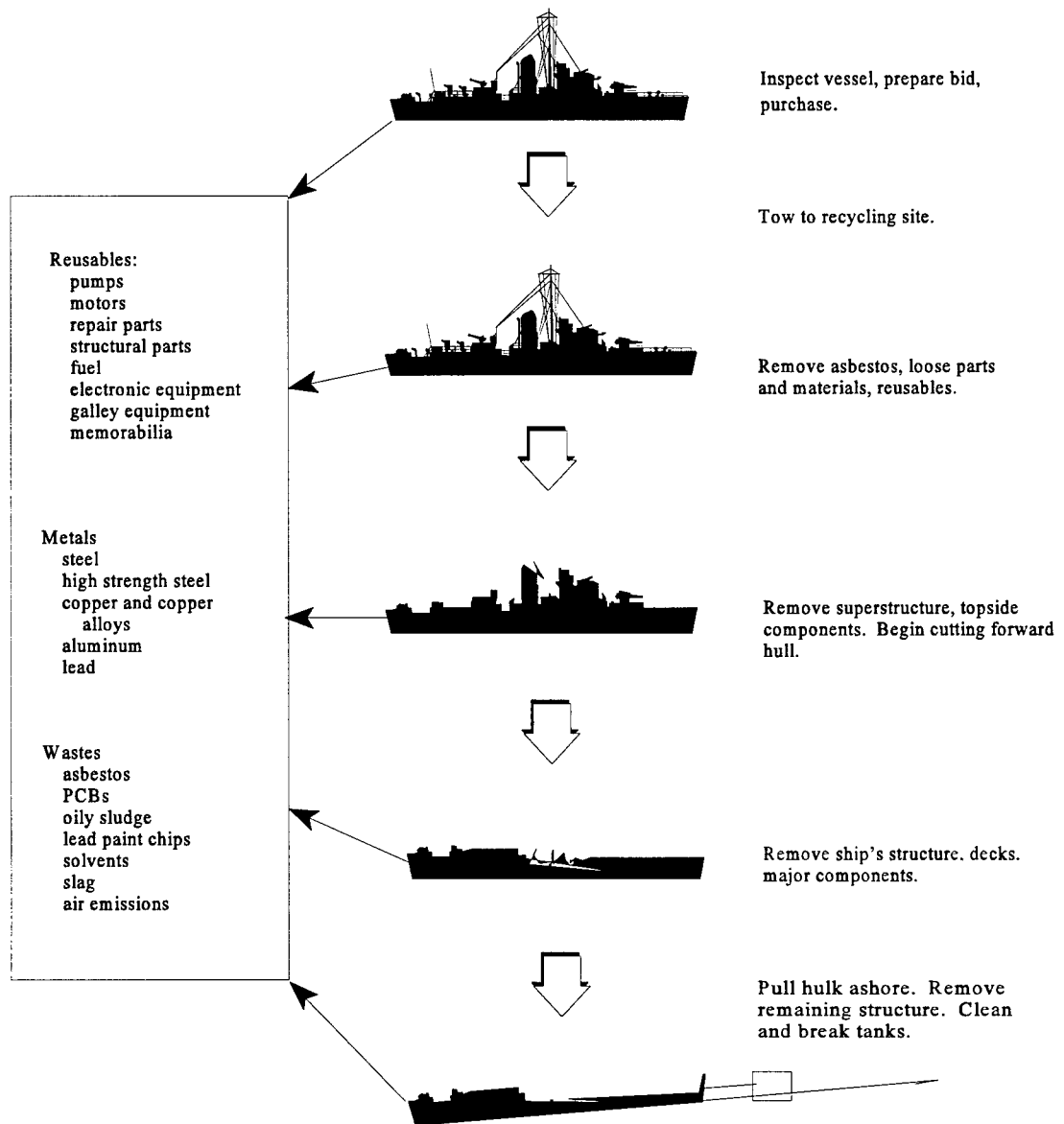
Submarines are recycled at Puget Sound Naval Shipyard (PSNS) in drydocks. The ships are opened circumferentially (and at other suitable locations in the hull), and components and structure are removed as the hull is cut apart. The process, which is a special case, will not be covered here in detail but is described fully in U.S. Naval Nuclear Powered Submarine Inactivation, Disposal, and Recycling, March 1995, (Reference 8).

2.1.2 Sale of Materials

Scrap metal, principally steel, is the primary economic resource in recyclable vessels. Metals are sorted by grade and composition and sold to smelters or to scrap metal brokers. Some recyclers operate mini-mills where the metals are remelted and formed into new products.¹

¹ Personal communication, MSCL Inc. (Burritt) and Schnitzer Industries (Zelenka), June 15, 1995.

Figure 1
Ship Recycling Sequence



Some components are resold for service elsewhere. Reusable materials and equipment are sold directly with little or no refurbishment at the recycling yard.² Ship propulsion machinery that is certified to be in conformance with the requirements of a recognized classification society, such as the American Bureau of Shipping, may be resold at a premium price for use in other ships if not obsolete or worn out. (Uncertified machinery is usually sold as scrap metal.)

Other than small craft and barges that are uneconomical to export, only U.S. Navy warships and submarines have been domestically recycled in recent years. After removal and disposal of the reactor compartments, the U.S. Navy has recycled the remains of up to 20 submarines per year, producing up to 30,000 tons of iron and steel scrap and another 14,000 tons of assorted metal scrap such as lead, copper and aluminum. Navy surface ship sales to domestic scrappers have averaged about 55,000 tons per year since 1990, representing about 30,000 tons of iron and steel scrap and 25,000 tons of other metals.³

From 1990 to 1995, an average of about 360,000 tons of U.S. commercial ships were sold yearly for scrap, all overseas. Of this, about 250,000 tons were privately owned ships and the balance, MARAD ships. Had all of the commercial ships been scrapped in the United States, they would have represented from 1 to 2% of the domestic iron and steel scrap market.

The value of the metals recovered from ships varies with the market price. Copper and copper alloys, for example, represent a small fraction of the total weight of the metals recovered from a ship, but return a large fraction of the revenue because of their high value.⁴ Table 1 lists the approximate relative value of the metals and reusable components recovered from recycling U.S. Navy destroyers and submarines.

These issues are discussed in detail in Maritime Administration, Report MA-ENV-820-96003-F, *The Markets, Cost and Benefits of Ship Breaking/Recycling in the United States*, July 1997.

² Personal communication, MSCL Inc. (Rushworth) and Wilmington Resources Inc. (Tomlinson), October 5, 1995.

³ Courtesy of Mr. Glen A. Clark, Naval Sea Systems Command, March 29, 1996.

⁴ The *Iron Age Scrap Price Bulletin*, March 25, 1996, cites scrap prices for iron and steel scrap ranging from \$15 to \$202 per ton depending on scrap quality, dimensions, and location. The dealer's price for copper is cited as \$0.82 per pound (\$1837 per ton).

**Table 1. Relative Weight and Value of Materials Recovered
During Recycling of U.S. Navy Destroyers and Submarines**

Material	Destroyer*		Submarine†	
	% of Total Scrap Weight	% of Value	% of Total Scrap Weight	% of Value
Steel	56	24	69	24
Lead	31	26	18	22
Copper and Copper Alloys	4	36	6	43
Aluminum	2	5	2	4
Stainless Steel	2	5	2	4
Miscellaneous Metals	1	2	1	2
Reusable Components	4	2	2	1

* Estimates courtesy of Wilmington Resources, Wilmington, NC, based on recycling of DDG 2 (CHARLES F. ADAMS) Class destroyers.

† Personal communication, MSCL Inc. (MacKinnon) and Naval Sea Systems Command (Orr), October 1995.

2.1.3 Waste Management

The wastes generated from recycling ships include both hazardous wastes and nonhazardous industrial trash. A wide variety of hazardous (or potentially hazardous) materials can be found in old ships⁵ including:

- Nonmetallic materials such as rubber, plastic and fabric parts, electric cable insulation, gaskets,
- Asbestos thermal insulation,
- Paint containing lead, chromium and PCBs,
- Metal parts with cadmium plating,
- Fluorescent light bulbs containing mercury,
- Oily sludge and unused fuel,

⁵ Maritime Administration, Report MA-ENV-820-96003-D, *Sampling and Analysis*, July 1997, reports the results of hazardous material sampling that was conducted in three ships in the MARAD inactive ship fleet.

- Bilge water, ballast water, and antifreeze solutions containing hazardous materials, and
- Storerooms with partly used containers of adhesives, paints and solvents.

With few exceptions such as fuel, these materials are not reusable and must be managed as hazardous and toxic wastes in accordance with Federal and state rules and regulations.⁶

Reference 5 describes the hazardous materials found in three MARAD ships and the actions required to remove and dispose of them in accordance with Federal regulations during the preparation of ships for export for recycling.

Hazardous waste management is a significant part of the recycling process. In one year, for example, the PSNS recycled all or parts of 20 submarines, producing about 6.3 million pounds of PCB-containing waste materials, about 0.3 million pounds of asbestos waste, and about 0.7 million pounds of other hazardous wastes. About 7 pounds of hazardous waste were produced for every 100 pounds of recyclable metal. About 40% of the total recycling cost was for environmental compliance, of which 90 cents of every dollar was for management of PCB wastes.^{7, 8}

Hazardous and toxic wastes generated during recycling are sent off-yard for incineration or burial; asbestos is bagged and sent to landfills; petroleum wastes are recycled, burned for energy recovery, or incinerated; and waste water is collected and processed to meet local requirements before discharge or is sent away for disposal. Some new waste management technologies that may help recycling yards deal with these problems are discussed in Chapter 5.

2.2 DOMESTIC SHIP BREAKING/RECYCLING

In the early 1980s, the nation's largest ship recycler, the Southern Scrap company in New Orleans, closed. In 1984, the National Metals company in Los Angeles, a firm that once produced up to 6,000 tons of scrap per month, closed because of falling scrap steel prices⁹ and

⁶ Most of the safety and environmental rules applicable to ship breaking/recycling are found in Titles 29 and 40 of the Code of Federal Regulations. Many states either have their own environmental rules or enforce the Federal regulations. References 2 and 3 discuss the environmental statutes, rules and regulations that apply to ship breaking/recycling, including those applicable to waste management.

⁷ Personal communication, MSCL Inc. (MacKinnon) and Naval Sea Systems Command (Orr), October 1995.

⁸ The data reported equal the total weight of material designated as PCB waste, hazardous waste, or asbestos waste, as applicable. For detailed information on the designation of hazardous wastes at PSNS and the concentration of hazardous constituents that cause a waste to be designated as hazardous, refer to the Washington State Dangerous Waste Rules.

⁹ The composite price for scrap steel in Chicago was \$56.14 per ton in January 1983 and generally stayed below \$75 per ton until midway through 1987. From mid-1987 through 1994, prices fluctuated between \$85 and \$138 per ton. For the past year, the price has been above \$130 per ton. Sources: Serjeantson, *Metal Bulletin's Prices & Data*, Metal Bulletin Books Ltd., 1994. Commodity Research Bureau, *The CRB Commodity Yearbook*, John Wiley & Sons, Inc., 1994. *Iron Age Scrap Price Bulletin*, March 25, 1996.

increasingly expensive environmental requirements.¹⁰ Since that time, nearly all domestic commercial ships have been exported overseas for recycling, and the remaining domestic recyclers have been left with small vessels, barges, oil rigs, and former U.S. Navy and other government vessels that, for reasons of security, potential military value, or government policy, must be scrapped in the United States.¹¹ Nine organizations in the United States—eight private firms and one government yard—remain active in the recycling of Navy vessels.¹²

The practice of exporting ships overseas may be changing, however, because of environmental problems. Beginning in 1989, the U.S. Navy began finding that many nonmetallic materials such as gaskets, electric cables, and rubber parts in Navy warships contained PCBs at concentrations in excess of the amount the U.S. Environmental Protection Agency (EPA) allows in domestic or overseas commerce.¹³ Similar materials have been found in U.S. Coast Guard ships, and References 4 and 5 confirm their presence in three typical old MARAD ships. This discovery has recently brought a halt to the export of MARAD vessels for recycling. Eventually this may provide additional hulls to domestic recyclers, but as of this writing, MARAD has not yet decided the future course of its ship disposal program.

2.3 FOREIGN SHIP BREAKING/RECYCLING

The focus of this report and the others in this series is the domestic U.S. ship breaking/recycling industry. However, foreign competition is partly responsible for the decline of the industry.

In past years, ship breaking/recycling firms in Asia have bought most of the U.S. ships destined for recycling.¹⁴ Many Asian countries need a source of metals for their developing industries but are burdened with old, inefficient steel production plants. As shown in Table 2, for example, many steel plants in India use more than twice the amount of energy to produce a ton of steel from iron ore as do modern plants in developed countries.

¹⁰ From *New Steel Magazine*, February 1995.

¹¹ Borsecnik, *Scrap Processing and Recycling Magazine*, May/June 1995, pp. 63.

¹² Puget Sound Naval Shipyard, Bremerton WA; Seawitch Salvage Co. Inc., Baltimore MD; Wilmington Resources Inc., Wilmington NC (recently re-formed under the name Sigma Recycling); The Best Group, Brownsville, TX; Transforma Marine, Brownsville, TX; International Shipbreaking, Brownsville, TX; Saber Steel, Brownsville, TX; Northern Marine, Portland, OR; and Peck Iron and Metal, Richmond, VA are active as of this writing. New firms often are formed when recycling opportunities arise. Other naval shipyards perform partial recycling of some Navy submarines prior to final recycling at PSNS.

¹³ Generally, levels of PCBs at or above 50 parts per million by weight in any liquid or solid (40 CFR 761).

¹⁴ Borsecnik, *Scrap Processing and Recycling Magazine*, May/June 1995.

**Table 2. Comparison of Energy Requirements
for the Production of Steel from Ore**

Country	Average Gigacalories Consumed per Ton of Steel Produced
Japan	4.01
Germany	5.20
Korea (Pohang plant)	5.21
United States	6.00
India (Bhilai plant)	8.90
India (Bokaro plant)	10.81
India (Pourkela plant)	11.12
India (Durgaphur plant)	11.45

Source: World Resources Institute, *World Resources, 1994-1995*, Oxford University Press 1994.

Asian ship breaking/recycling firms have several advantages:

- A ship is a very competitive source of scrap. An old freighter containing 8,000 tons of recyclable steel and 1,000 tons of other recyclable metals might be purchased for about \$800,000 (\$90 per ton) and towed to Alang, India (a large shipbreaking site) for an additional \$500,000—a total of \$1.3 million. For about the same price, an Indian importer would be able to purchase and import 8,000 tons of processed scrap steel, with no copper or other valuable metals.¹⁵
- Labor to break the ship is inexpensive, no more than \$3 per day (at current exchange rates) in India, compared to about \$112 per day in pay, benefits, tax and other burdens for a U.S. counterpart.
- There are lower costs for protection of the environment and worker safety. The standards are not as stringent as those in the United States, as discussed in Reference 2.

¹⁵ Estimates courtesy of Wilmington Resources, Wilmington, NC; and Jacobson Metal Company, Chesapeake, VA.

- There are large demands for rerolled products such as concrete reinforcing bar made directly from plate steel recovered from vessels.¹⁶
- Despite working conditions that most U.S. workers and employers would find unsatisfactory and even illegal, ship breaking/recycling provides employment opportunities in countries where unemployment is high.

2.4 CONCLUSIONS

The low scrap prices in the early 1980s, together with escalating environmental requirements, forced out much of the domestic ship breaking/recycling business. Scrap prices recently have risen¹⁷ while, at the same time, environmental problems have restricted export of MARAD ships. These new trends suggest that the industry may recover, particularly if cost-effective solutions to environmental problems can be developed and new technologies can be employed to overcome high labor costs.

¹⁶ Ibid.

¹⁷ The U.S. Geological Survey Mines FaxBack for Iron and Steel scrap reports that the U.S. average price for No. 1 heavy melt scrap has risen from \$83.88 per ton in 1992 to \$130.00 per ton in 1995.

3.0 CURRENT TECHNOLOGY AND PROCESSES USED FOR DOMESTIC SHIP BREAKING/RECYCLING

3.1 GENERAL

The key technologies and technical processes currently used for ship breaking/recycling are discussed below. All of the technologies that are described are available from a number of competing manufacturers. The report focuses on the technical aspects of ship breaking/recycling that may be notably improved by a new technology. Background technology, such as electric power production and distribution, is not assessed.

The report is organized to follow a ship through the recycling process, from arrival and initial preparation for metal cutting to final disposition of the wastes.

3.2 CUT-LINE PREPARATION AND CLEANING OF SURFACES

Many interior surfaces in ships are coated with insulating materials and layers of paint and insulation adhesives. These materials must be removed before cuts are made in order to avoid fires, the formation of toxic combustion products, and the release of insulation dust.

During recycling of Navy surface ships, manual removal of thermal insulation and combustible materials in the way of cut lines is sufficient. However, the interior surfaces of submarines are often coated with layers of anti-sweat insulation, adhesives, paint, and sound dampening materials that not only are flammable but also are contaminated with PCBs that form highly toxic dioxin and furan fumes when heated.¹ Therefore, very thorough cleaning is performed before cutting.

Having tried solvents, needle guns, scrapers, grinders and many other methods, Puget Sound Naval Shipyard has found grit blasting to be the most effective. Many different grits have been tried, including minerals, steel shot, and steel grit. The most effective is steel grit. Sand and mineral grits are the least expensive per pound and are efficient cleaners but they degrade to dust during one use, add to the waste volume, and may expose workers to harmful sand or mineral dust. Steel shot is dangerous for workers to walk on and tends topeen surfaces and entrap contaminants rather than cut cleanly to bare metal.² Table 3 compares the characteristics of some grits that were tried.

¹ Dioxin and furan compounds are both extremely toxic products of the incomplete combustion of many chlorine-containing organic materials, particularly PCBs.

² Personal communication, MSCL Inc. (MacKinnon) and PSNS (Kelly), September 20, 1995.

Table 3. Comparison of Blasting Grits

Grit	\$/lb	# Cycles	Safety
Sand	0.01	1	Dust Hazard
Black Beauty	0.42	1	Dust Hazard
Steel Shot	0.48	>10	Slip Hazard
Steel Grit	0.50	>10	-----

Steel grit blasting is also used to clean parts that are coated with PCB paints or residues before they are cut or remelted.

Steel grit is suitable for use in closed loop systems. The used grit and debris are fed as they are generated to a recovery system where the debris is separated and the grit returned to the blast gun. The system reduces the volume of grit needed and the volume of waste to be disposed of, and precludes the need for a separate system for separation of grit from the waste. A typical system is illustrated in Figure 2.³

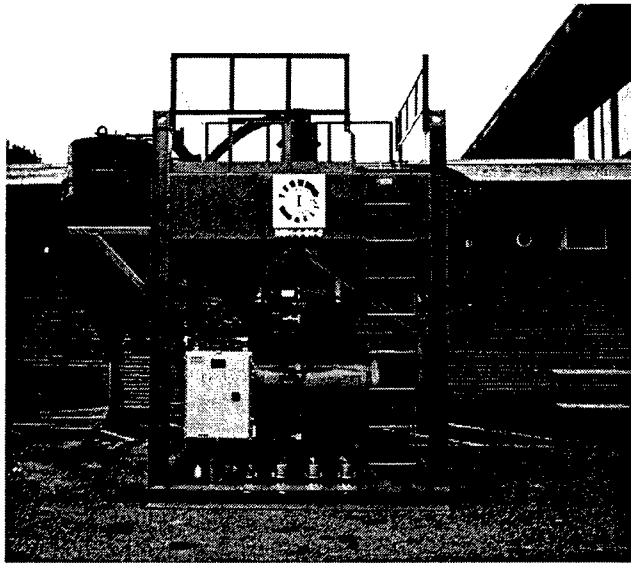
Typical systems will blast 60 to 250 square feet per hour, depending on the nozzle size and the amount of air provided. A system that feeds four blasting nozzles costs about \$20,000 and will last at least 20 years. There is no required periodic maintenance other than blast tip replacement.

3.3 SECTIONING AND LIFTING

The steps to reduce a ship that is several hundred feet long to small pieces, suitable for remelting furnaces, must be carefully planned to minimize cost. The number and size of the pieces that can be cut from a ship, the number and capacity of cranes and forklifts available to move them off the ship to processing stations elsewhere in the yard, the capabilities of the processing stations to cut up and sort the metals, and the capacity of the rail car or truck loading systems must all be coordinated so that the materials flow smoothly through the process with minimum labor and without delays along the way. Each recycler must decide how best to coordinate his or her process. Labor pay rates afloat and ashore, crane capacities, the availability of laydown areas where further cutting can be performed, the vessel size, railroad siding capacity, and many other factors affect the decisions. One recycler has found it most economical to section ships into large pieces weighing up to 30 tons and move them ashore for further reduction, sorting, staging

³ Courtesy of Safe Systems Inc., Kent, Washington.

Figure 2. Mobile Steel Grit Blasting System



and rail car loading.⁴ Another cuts the ship directly into small pieces aboard the ship and uses available space on the hulk for sorting and staging.⁵ A third found that cutting pieces limited to about 20 tons permitted large forklifts to perform many of the movements, relieving a choke in the process theretofore caused by the limited speed of the overhead crane systems.⁶

A wide variety of heavy lift equipment can be employed. Railroad cranes, mobile (crawler) cranes, forklift trucks, and loaders are available from many domestic and foreign manufacturers.

3.4 METAL CUTTING

Metals are cut with a variety of torches, saws, and shears. Oxygen-fuel torches used on many types of steel operate on the principle that iron, when sufficiently hot, reacts vigorously with oxygen, releasing heat that forms molten oxides and melts the metal itself. Electric arc or plasma arc cutters generate temperatures high enough to liquefy almost any metal and also can employ excess oxygen in the manner of oxygen-fuel torches. Mechanical cutters such as saws and shears operate on the same principle as household saws and scissors, but on a larger scale. Examples of the torches, saws, and shears that are currently in use at domestic ship recyclers are discussed in turn.

⁴ Personal communication, MSCL Inc. (Rushworth) and Wilmington Resources Inc. (Tomlinson), October 5, 1995.

⁵ Personal communication, MSCL Inc. (Shaw and Burritt) and Seawitch Salvage Company, Inc. (Ellis), July 19, 1995.

⁶ Personal communication, MSCL Inc. (MacKinnon) and PSNS (Kelly), September 20, 1995.

3.4.1 Oxygen-Fuel Torches⁷

Modern oxygen-fuel cutting torches are the tool of choice for cutting steel. Torches burn a wide variety of fuel including acetylene, propane, butane, fuel gas, natural gas, and MAPP[®] (methoxyacetylene dipropene) and use either oxygen or liquid air as the oxidizer and “cutting gas” that serves to burn (oxidize) iron along the cut line. Oxygen-fuel torches operate with a flame temperature of 3,500° to 4,000°F and flame velocities of 290 to 425 feet per second. When cutting steel, the torch flame heats the cut line to red-hot temperatures (about 1400°F). Excess oxygen is then injected into the flame to chemically react with iron, form molten iron oxide (that melts at a lower temperature than steel) and blow the molten mass away from the cut line (the kerf). Cutting speeds for 3/4-inch steel range from 17 to 26 inches per minute depending on the fuel, oxidizer and torch tip chosen.

The technology of oxygen-fuel cutting torches is highly developed. Dozens of different styles of torches and torch tips are available depending on the type and supply pressure of the fuel and oxidizer, the thickness of metal to be cut, and the environment where the work is done. For very thick metal, separate long hollow tubes (lances) are used to feed oxygen to the kerf, which is heated by a separate torch. Figure 3 illustrates typical torch tip configuration, and Figure 4 a typical oxygen-fuel cutting torch.

Figure 3. Typical Oxygen-Fuel Cutting Torch Tip Configuration

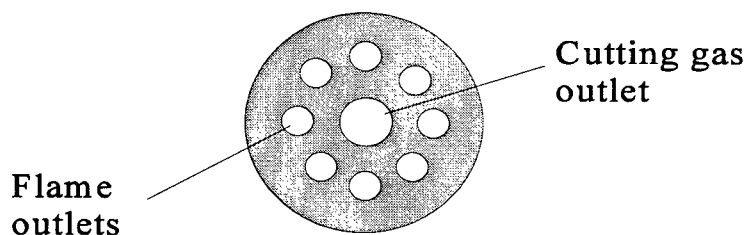
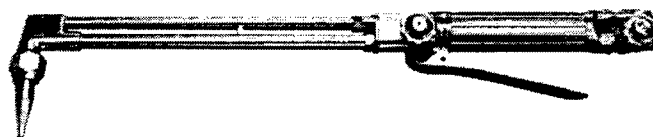


Figure 4. Typical Oxygen-Fuel Cutting Torch



⁷ Much of the information in this section is from Althouse et al., *Modern Welding*, the Goodheart-Willcox Company, Inc., 1988.

Acetylene and propane are popular fuels. Table 4 compares the key features of an acetylene and propane torch system.⁸ Although propane torches cut more slowly than acetylene torches because propane does not burn as hot, propane is much less expensive and is the fuel of choice in most modern domestic ship breaking/recycling yards. PSNS has found that MAPP[®] gas, which burns almost as hot as acetylene, is best for cutting the thick steel of submarine hulls.

Table 4. Oxyacetylene and Oxypropane Torch Characteristics

	Acetylene	Propane
System Purchase	\$350 to 600	\$350 to 600
Fuel Cost (per hour of operation)	\$6.00	\$3.20
½ Steel Cutting Rate	20-24 in/min	18-22 in/min

Acetylene torches cannot be operated continuously as can propane or MAPP[®] torches. Acetylene gas is dissolved in acetone, and when withdrawn from the cylinder, the acetone chills, acetylene pressure gradually falls, and within an hour the gas pressure is too low for the torch. An hour's wait will warm the cylinder and restore pressure, but work is delayed. A large manifold acetylene system can overcome this problem, but the higher fuel cost of acetylene has driven the industry to propane.

Both liquid and compressed oxygen are used to provide oxygen to oxygen-fuel torches.

Torch cutting releases large amounts of metal fumes and smoke to the atmosphere. Under present environmental and safety rules, it is not heavily restricted; however, recent changes in the Clean Air Act, discussed in References 2 and 3 may lead to increased restrictions on such emissions.

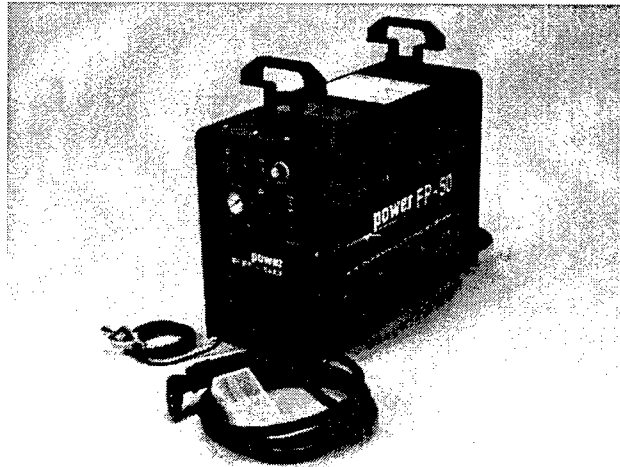
Oxygen-fuel torches are effective for cutting steel. Metals that form oxides that do not melt at a temperature less than the base metal, such as copper nickel, are difficult to cut with these torches. With practice, an operator can learn to manipulate the torch to blow away molten metal and blow off oxide deposits as they form and successfully cut such metals, but the process is slow. Also, powdered iron or aluminum can be fed to the kerf through special torches to react with the oxygen and form desirable low-melting oxides; however, these systems suffer from frequent clogging of the tip orifice through which the powdered metal is injected. These and other adaptations of the oxygen-fuel torch system have been developed to cut nearly any metal, but the cutting rates are often slow, and other cutting methods, such as plasma arc torches or saws, are normally used instead.

⁸ Courtesy of Victor Equipment Company, Denton Texas.

3.4.2 Electric Arc Torches

Electric arc torches generate heat for melting metal by the discharge of electric arcs. Two different approaches are used: 1) an electric arc is struck between the metal to be cut and an electrode in the torch handle generating heat in the metal, or 2) an electric arc is struck inside the torch head and heats a “shield gas” to extremely high temperatures, forming a plasma which jets from the torch handle and heats the metal to be cut. In some applications, the latter approach adds an arc between the torch handle and the metal being cut, combining both principles. Electric arc torches can generate extremely high temperatures and can melt and cut almost any metal. A typical plasma arc cutting system, employing air as the cutting gas, is illustrated in Figure 5.

Figure 5. Air Plasma Arc Torch System



Automatic electric arc torches used for cutting metals in production lines can be optimized to cut very rapidly: up to 140 inches per minute on 0.25-inch-thick steel. Manual torches are much slower than oxygen fuel torches in typical ship breaking/recycling environments, cutting at rates of no more than 10 inches per minute. However, they are able to cut any metal with equal ease. A cutting gas is required to blow away the molten metal, and air is often used. Oxygen will speed the cutting rate of steel by the same iron-oxygen reaction that occurs with an oxygen-fuel torch, but both air and oxygen attack the electrode, shortening its life. Electrode life can be prolonged by using argon for the cutting gas, but cutting of steel is slower and argon itself is more expensive. Carbon electrodes are often used, but hafnium is coming into use with air and oxygen gas. Tungsten is often used with inert cutting gas.

A plasma-arc torch system costs from \$10,000 to \$15,000 and consumes from 9 to 17 kilowatt-hours of electric energy per hour. At a cost of about \$0.07 per kilowatt hour (Virginia Power), a plasma-arc torch will consume up to \$1.20 per hour of electricity.

Aside from a slow cutting rate, there are other limitations inherent in plasma arc systems:

- High voltage DC (direct current) provided to the electrodes suffers from pronounced I^2R losses (electric resistance heating) if the cables are over 15 feet long.
- The torch handle must be held at a constant, nearly perpendicular angle with respect to the surface of the metal being cut and for this reason is difficult to use on the corners and curves that are frequently encountered in ship breaking/recycling.

3.4.3 Underwater Cutting

Underwater cutting is sometimes required to remove propellers and propeller shaft supporting structures so that a ship can be more easily pulled ashore during the terminal stages of recycling. Underwater cutting systems use the same principles described above, except that the kerf is "shielded" by high-volume air blankets to keep water momentarily away. Oxygen-fuel underwater torches often use MAPP[®] gas because it can be delivered at a higher pressure than acetylene (to overcome the back pressure of the water) and burns hotter than propane.

3.4.4 Metal Cutting Saws

A variety of electric power metal cutting saws are available, including those with circular and reciprocating blades. Both types are capable of cutting nonferrous metals up to 2 inches thick at rates ranging from 36 inches per minute for 1/4-inch-thick metal to 20 inches per minute for 1-inch metal. Saw drivers cost from \$200 to \$1000 each, run on 110 or 220 volt AC power and last indefinitely with care.⁹ Blades must be replaced every few weeks of use but are inexpensive, ranging up to \$40 each. Saws can be used only on nonferrous metals. Frictional heating of the cutting edge of the blade on ferrous metals will cause oxidation of iron, very high temperatures, and instant destruction of the blade.

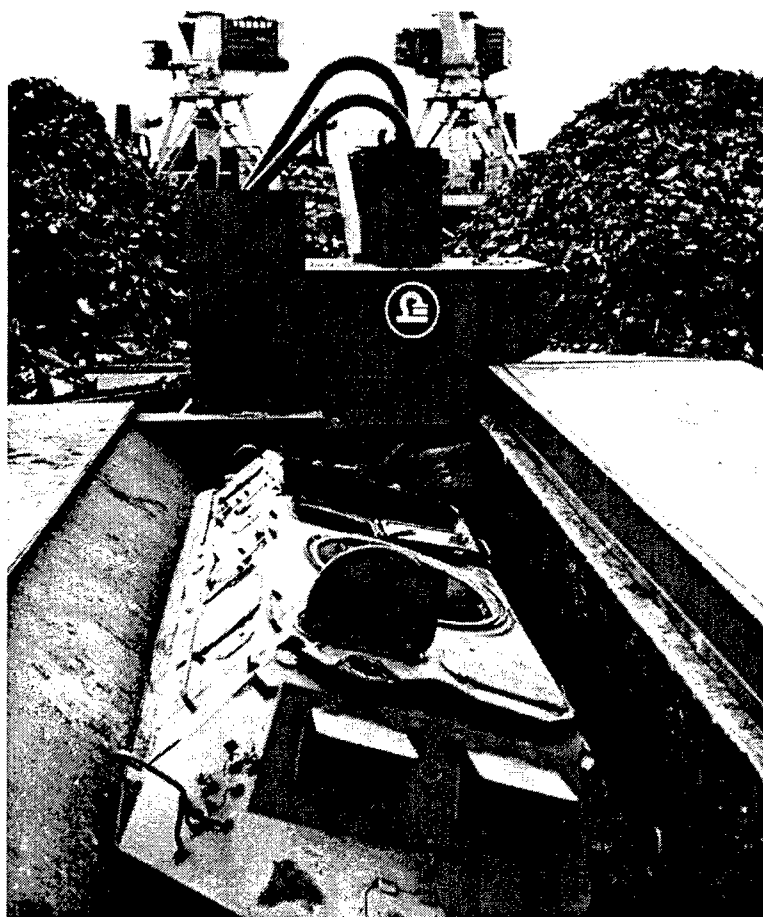
3.4.5 Shears

Large industrial shears, some specifically designed for ship breaking/recycling, can quickly reduce large metal parts to small dimensions, suitable for a remelting furnace, with less labor than torch or saw cutting. There are dozens of different sizes of stationary and mobile shears available, and some ship recyclers use them. Stationary shears range in size from devices suitable to cut up small pipes and tubing to very large machines capable of shearing sections of hull plate up to 13 feet wide and 29 feet long. Mobile shears, mounted on tractor crawlers, powerful enough to shear plating and structure directly from ships, are used at some recyclers. Large shears have cutting rates measured in tens of feet per minute, compared to inches per minute for torches. Some large stationary shears include pre-compression or "boxing" devices which can compress irregular objects and metal debris into a log-shaped mass before cutting.

⁹ Courtesy of American Carbide Saw Co., Hatboro, PA.

Figure 6 illustrates a large stationary shear.

Figure 6. Stationary Boxing Shear Ready to Box and Shear An Armored Personnel Carrier Cabin



The thickness, toughness, and dimensions of the metal to be sheared, the required cutting rate, and the product dimensions are important for selecting the correct machine for the service. Table 5 shows the capabilities of a range of large stationary machines suitable for shearing steel plate.¹⁰

¹⁰ Harris Waste Management Group, Inc., *ABS Shears*.

**Table 5. Typical Stationary Shear
Capacity and Dimensions**

Model	1	2	3	4
Shear Force (tons)	500	550	803	1016
Cuts/min	4.5	3.5	4	4
Production Rate (tons/hr)	13	13	18	22
Horsepower	100	100	200	300
Gross Weight (tons)	80	98	110	177
Height	16'8"	20'11"	20'6"	21'9"
Width	15'11"	18'3"	18'5"	21'5"
Length	54'3"	48'4"	49'4"	62'10"

PSNS has experimented with mobile shears for cutting up submarine hulls in drydocks. Because of the extraordinarily thick and hard metals in submarines, very high cutting pressures were required, sometimes creating high velocity projectiles from the cut steel, endangering workers in the drydock. Also the shears were cumbersome and slow when operating within the confines of a drydock. PSNS concluded that they are unsuitable and no longer uses them¹¹; however, other recyclers have used them successfully on surface vessels.¹²

3.5 SHREDDING AND SEPARATING

Recyclable metal that is intermixed with useless nonmetallic material can be recovered for reuse by using shredders and separators. Shredders and separators are rarely if ever used to process hull and structural metals from ships because these products are usually recovered in large pieces, free of significant nonmetallic material. However, shipboard electric cables (about 75% by weight copper) are often shredded for recovery of the copper by recyclers specializing in this process. Recyclers of automobiles, white goods, and other small waste objects consisting of complex mixtures of metals and nonmetallic materials also use shredders and separators.

Shredders first reduce the parts to a gravel-like mixture of metal particles and nonmetal "fluff." Shredders operate on a number of different principles. Some use spinning blades, much like home garbage grinders, while others have flails that literally beat the feedstock to particles. Hundreds of different shredders are available, ranging from machines with dimensions of a few feet, designed for shredding tires and other small objects, to massive machines capable of

¹¹ Personal communication, MSCL Inc. (Rushworth) and PSNS (Shipley), October 12, 1995.

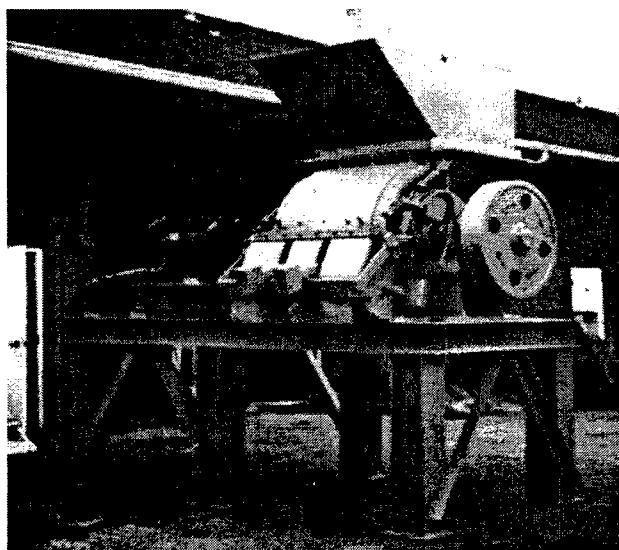
¹² Both Wilmington Resources and Jacobson Metals report the successful use of mobile shears to cut apart surface vessels. Note that Jacobson has not recycled ships recently but has used mobile shears on large barges.

shredding automobiles. Table 6 lists the properties of one manufacturer's series of shredders designed for shredding aluminum and other soft scrap, and Figure 7 illustrates a typical small shredder.¹³

Table 6. Shredder Capacity

Model	Feed Opening		Horsepower	Shredder Head Weight (lbs)	Capacity (lbs/hour)
	Length (in)	Width (in)			
1	28	17	Up to 25	3900	Up to 2,500
2	36	25	Up to 40	5200	Up to 8,000
3	51	25	Up to 60	9000	Up to 9,000
4	50	35	Up to 150	16500	Up to 2,000
5	54	40	Up to 300	23500	Up to 4,000
6	64	40	Up to 300	28000	Up to 8,000
7	72	52	Up to 400	36000	Up to 12,000
8	95	52	Up to 600	40000	Up to 16,000
9	105	72	Up to 800	55000	Up to 28,000

Figure 7. Small Shredder



¹³ Courtesy of Counselor Engineering, Hudson, Ohio.

After the shredding, the metals are separated from the fluff by several means. Magnetic separators are often used for separation of steel. Air flotation separator columns, which lift fluff free of the heavier metals, and shaker tables work well where the shredded metal is much heavier than the fluff. To select the right shredding and separating equipment, the recycler considers the dimensions of the feedstock, the toughness and composition of the metals and nonmetals in the scrap, the desired purity of the shredded product, and the cost of competing systems. In most recycling yards, shredders and separating equipment are arranged in series with conveyor belts and air lifts to move materials through the process in a continuous stream.

Periodic maintenance on shredders and separators includes replacement of shredder cutter blades and conveyor belts every few months.

Some shredder feedstock contains hazardous materials, such as asbestos or PCBs, that may be difficult to contain and effectively separate from the metals during the shredding and separation process. Regulating agencies require special licensing of shredding operations to ensure that such hazards are properly controlled during shredding and separation and that the metals and fluff are properly managed thereafter.¹⁴ For a discussion of the regulations that may apply to shredding and other ship breaking/recycling operations, see References 2 and 3.

3.6 MINI-MILLS

At least one major U.S. metals recycler, though not presently active in ship breaking/recycling, operates small steel mills (mini-mills) close to scrap operations.¹⁵ This reduces transportation costs for scrap and provides another source of profit for the firm. Waste processing technologies may also improve the profitability of domestic recyclers. These are discussed in Chapter 5.

3.7 OCCUPATIONAL SAFETY AND HEALTH TECHNOLOGY

Ship breaking/recycling is a heavy industry subject to the safety and health requirements of all heavy industry in the United States. The applicable statutes, rules and regulations are discussed in References 2 and 3. These rules and regulations require the use of specific personnel safety equipment, depending on the circumstance faced by the worker. For example, to reduce injuries from falling and moving objects, rigid helmets (hard hats) and hard-toed shoes are required in most areas of a ship breaking/recycling yard. Also, workers using cutting torches must often wear leather welder's gloves and protective suits (to protect from spatter) and welder's helmets (to protect the eyes). Asbestos workers must wear full-body protective suits, head covers, and air breathing masks to ensure that workers neither breathe nor come in bodily contact with asbestos dust.

¹⁴ H.E.L.P.E.R. Inc of Madison, SD has been working with EPA to be licensed to shred PCB-contaminated electric cable from the U.S. Navy.

¹⁵ Personal communication, MSCL Inc. (Burritt) and Schnitzer Industries (Zelenka), June 15, 1995.

There are many administrative health and safety protections afforded workers. They must be fully informed about workplace hazards. They have rights and responsibilities to report problems and conform to the rules. All these requirements are laid out in applicable rules, but none is unique to the industry or has unique applications. However, there are some new technologies which could be used to reduce the hazards. More extensive use of large shears would reduce generation of the metal fumes that accompany oxygen-fuel torch cutting and worker exposure to this hazard. Several new technologies which could mitigate worker exposure concerns are discussed in Chapter 5.

3.8 EQUIPPING A BREAKING/RECYCLING YARD

Ship breaking/recycling can be performed almost anywhere where there is water deep enough to bring a ship near shore. Some ship breakers/recyclers have used nothing more than a beach, and others, a fully equipped shipyard. The type and amount of new equipment needed to begin ship breaking/recycling at any particular location will be influenced by facilities and equipment already at the site, the type of ship being scrapped, the market requirements for the scrap, and many other variables. Therefore, no single list of equipment will be correct for each circumstance. However, Table 7 provides a rough estimate of the value of the equipment needed for a yard capable of ship breaking/recycling 10 ships per year. The list assumes that a site is available with buildings, a place to pull ships ashore, but little else. The assumptions are:

- Ship breaking/recycling will be done afloat,
- Rail and road transportation services are available,
- There are adequate buildings for offices, storage of reusable equipment, artifacts, and materials but there is no lifting equipment,
- There is a slip with adequate water depth that enables mobile cranes to lift materials off and there is an area to pull the remaining hulk ashore as material is removed, and
- New equipment will be purchased.

Ship breaking/recycling in drydocks or constructing transportation facilities, buildings or a slip would add to the cost of outfitting a site, whereas purchase of used equipment would substantially reduce the cost.

**Table 7. National List of Equipment for a
Ship Breaking/Recycling Yard**

Type of Equipment	Number	Unit Price	Total Cost
150 ton Crawler Crane	2	\$395,000	\$790,000
50 ton Crawler Crane	1	258,000	258,000
100 ft reach Hydraulic Counterbalancing Crane	2	600,000	1,200,000
140 Ton Mobile Shears	1	165,000	165,000
50 Ton Mobile Shears	1	95,000	95,000
Front End Loader	2	100,000	200,000
2,200 ton Automatic Baler-Shear	1	3,850,000	3,850,000
1,000 ton Automatic Baler Shear	1	1,400,000	1,400,000
20-Ton Fork Lift	3	45,000	135,000
125 cfm Air Compressor	3	30,000	90,000
Personnel Safety Equipment	20 sets	80,000	80,000
Plate Scale	1	10,000	10,000
Oil/Fuel/Grease Truck	1	25,000	25,000
Scrap Dump Truck	3	125,000	375,000
Winch	2	15,000	30,000
Diaphragm Air Pump	5	2,000	10,000
Fork Lift	10	3,000	30,000
Grit Blast System	3	75,000	225,000
Misc. Tools	1	35,000	35,000
Total			\$9,003,000

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4.0 CURRENT TECHNOLOGY USED FOR OVERSEAS SHIP BREAKING/RECYCLING

4.1 GENERAL

The technology employed by foreign ship recyclers ranges from modern to primitive. Facilities in Europe and Taiwan employ the modern cutting, lifting and transportation equipment described in the previous sections, while those in India, Pakistan, Bangladesh and parts of China scrap almost entirely with hammers, cold chisels and unskilled labor. Figure 8 illustrates a ship breaking/recycling operation in Bangladesh. Differences in foreign scrap markets lead to differences in the recycling approach. In the United States and Europe, nearly all metals recovered from ships are remelted and made into new products. In China, cleaned plate steel is often heated and rerolled directly into new products such as concrete reinforcing bar.

There are a few technological approaches employed by foreign scrappers that do not have common acceptance in the United States. These are discussed below.

Figure 8. Ship Breaking/Recycling in Bangladesh



4.2 ULTRALARGE STATIONARY SHEARS

Very large stationary shears, designed specifically for cutting the hull plating of ultralarge crude oil carriers to reroll plate, are in use at one foreign facility.¹ The shears are 52.5 feet wide, 95 feet long and 40.4 feet tall and can shear hull and structure plates up to 29.5 feet long by 13.25 feet wide. Because ultralarge crude carriers are not scrapped in the United States, there is no call for this machine here.

4.3 OTHER SHEARS

The U.S. Government, in support of international nuclear weapons control agreements, has provided several sets of large stationary and mobile shears to Russia. The shears are being placed in service at shipyards in Murmansk, Severodvinsk and Vladivostok to assist in the destruction of submarine missile compartments as required by Strategic Arms Limitations Agreements between the two countries. The shears are comparable to the equipment used in some domestic surface ship recycling yards and tested at the Puget Sound Naval Shipyard on U.S. submarines (and found unsuitable because of space restrictions in the drydocks where recycling is performed). It remains to be seen if this equipment is more suitable for use on Russian submarines at their shipbreaking facilities.

¹ Lindemann KG, *Shipbreaking Shears*, undated.

5.0 ADVANCED TECHNOLOGY POTENTIALLY APPLICABLE TO DOMESTIC SHIP BREAKING/RECYCLING

5.1 INTRODUCTION

Over the years, technological advances have significantly lowered the price and improved the quality of new domestic and foreign products of all kinds, from industrial intermediate materials such as sheet steel to finished consumer products such as automobiles. A few technical innovations have benefitted the recycling industry. Modern shears and shredding systems have reduced the manpower requirements for recycling everything from ships to refrigerators and kept the domestic recycling industry reasonably competitive with low-wage Asian competitors. But for the most part, technical innovation has not taken root in the ship breaking/recycling industry. There are many economic factors which have prevented this, including the following.

- Ships are large and cumbersome, too large to be quickly reduced to salable scrap. Buying a ship, moving it to a recycling yard, and cutting it to scrap can take months. During this time, scrap prices can vary significantly. For example, the domestic price for scrap steel varied from \$87 per ton in January 1993 to over \$130 per ton 2 years later.¹ On a single day, the price of scrap steel has varied among different cities from \$76 to \$144.²
- The supply of U.S. ships is irregular. During the last 10 years, the number of MARAD vessels sold for scrapping, all overseas, ranged from zero (1990 and 1995) to a high of 37.³ The supply of U.S. Navy ships has also been irregular during this period, ranging from as few as 1 (1991) to as many as 17 (1994).⁴
- Ships being scrapped are very old. Some built before World War II are just now entering the recycling market.⁵ They have all of the environmental problems of past years, including asbestos, high-lead paints, and PCBs. Compliance with modern and increasingly stringent environment, health, and safety rules, reviewed in References 1 and 2, adds significantly to the recycler's overhead cost.⁶

¹ *American Metal Market*, Vol 103, No. 140, July 24, 1995.

² *Iron Age Scrap Price Bulletin*, August 28, 1995.

³ Courtesy of Mr. Jeff Hirsch, Maritime Administration, March 14, 1996.

⁴ Courtesy of Mr. Glen A. Clark, Naval Sea Systems Command, March 29, 1996.

⁵ Eight Navy ships sold for scrap between 1992 and January 1996 were built before or during World War II.

⁶ Puget Sound Naval Shipyard has estimated that as much as 40% of the total cost to recycle a submarine arises from environment, safety and health issues.

- The prices offered by Asian recyclers for the purchase of old ships are much higher than those offered by U.S. recyclers. Between 1987 and 1994, MARAD received an average of \$106 per ton for ships sold for overseas scrapping. Recent prices for U.S. Navy warships, sold only for domestic recycling, average \$38 per ton.⁷

Some recycling yards have adopted some modern existing technologies, such as shears (see Section 3.4.5), but many advanced technologies, such as water jet cutting (Section 5.2.4) and modern industrial planning (Section 5.4), have yet to be tried. While many small advances have been made, the process remains labor intensive, and the economic conditions in the industry make long-term investment in advanced technology a risky enterprise. To overcome these difficulties, new technological solutions are needed. The best solutions would be technologies that are:

- Existing, proven, and virtually free of development cost,
- Relatively cost-effective to adapt and install,
- Able to reduce dismantling time or significantly reduce labor costs, and
- Able to reduce cost of compliance with environment and safety regulations.

These are difficult criteria for any technology to meet, but there are some that show promise. This section of the report focuses on promising technologies which fall into three major areas:

- Metals cutting. Some technologies have promise to speed the cutting process, and others may lower the release of airborne contaminants compared to torch cutting.
- Waste management. Domestic ship recyclers almost exclusively contract out for their waste disposal needs. Some new waste management technologies may provide for cost-effective on-site destruction of the wastes while producing salable products.
- Industrial planning. The profitability of domestic recycling may be significantly improved by developing a comprehensive plan for a recycling facility that makes use of best available technology to cut up ships and move materials through the necessary recycling stages quickly and with minimal manpower while properly controlling hazardous materials.

⁷ The Maritime Administration, Burdette Bidder Services Inc., and Defense Reutilization and Marketing Service.

5.2 METALS CUTTING TECHNOLOGY

5.2.1 The Fire-Jet® Torch System⁸

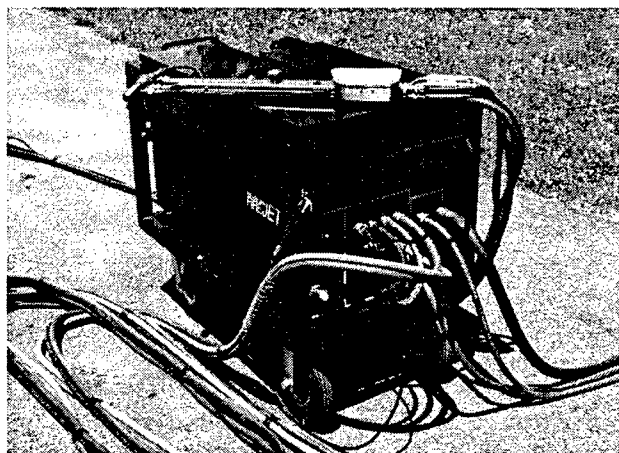
The Fire-Jet® torch is an imported Russian technology, patented both in the United States and globally, and now manufactured in the United States. Two separate torches come with the system. The FireJet® Model 500 is a conventional oxygen-fuel torch that uses pressurized kerosene as the fuel and, in every other respect, is the same as the oxygen-fuel torches described in Chapter 3. The Model 500 is expected to consume kerosene at a rate of up to 2 gallons per hour (about \$3.00 per hour) or about the same or less than a propane torch. This Russian technology has not yet been upgraded to incorporate state-of-the-art flow control valves and other high-quality features that will permit it to be used in this country. Although exact information on the torch operating characteristics is not available, there appear to be no impediments to successful system operation.

The FireJet® Model 1000 is a significantly different torch than the Model 500. It has been upgraded and is available for sale in the United States. Burning the same kerosene and oxygen as the Model 500, the Model 1000 is a small rocket engine that generates supersonic flame (Mach 2.8 or about 3,000 feet per second or 1,800 miles per hour) at claimed temperatures up to 8,000°F. This is comparable to the temperatures developed in electric plasma-arc torches and is sufficient to cut anything including reinforced concrete. The Model 1000 torch head requires water cooling to prevent the combustion chamber from melting. Both torches are served by a common control panel and fuel cart that holds the kerosene supply and pump and all electronic systems. The cart, along with a Model 1000 torch on top, is shown in Figure 9. The manufacturer advertises a FireJet® system, including support cart and one of each of the torches, at about \$13,000. This price does not include the oxygen or cooling water supply.

In its present manifestation, the Model 1000 does not employ excess oxygen to speed cutting of steel, although that appears to be a simple addition. Instead, it relies on the very high temperature of the flame and the force of the supersonic flame jet to melt and blow away metal from the kerf.

⁸ FireJet® Corporation and FireJet Systems.

**Figure 9. FireJet® Support Cart with
Model 1000 Torch on Top**



Unlike propane or acetylene torches, the Model 1000 is electrically ignited when the operator presses the trigger and it extinguishes when the trigger is released. This is a necessary safety feature because the torch head has a considerable reaction force that would cause the operator to lose control if it were dropped. It is also noisy, generating about 108 decibels (dB) of noise at the operator's position. Ear protection is therefore required and, because of the intense light of the flame and heated metals, eye protection is also required.

The manufacturer claims an operating life for the Model 1000 of over 4,000 hours. This should be equivalent to about 4 years of use. The Model 1000 will cut ferrous and nonferrous metals at the same time. This may be a significant advantage in an old ship where many different metals are present.

Under the sponsorship of the U.S. Department of Energy (DOE), the Diagnostic Instrumentation and Analysis Laboratory of Mississippi State University tested the FireJet® 1000 torch for cutting 4-inch-thick carbon steel. Flame temperature, fuel and oxygen consumption, cutting rate and other parameters were measured during the test. Table 8 summarizes the results and compares them with information on an oxypropane torch configured to cut 4-inch-thick steel.⁹

⁹ The cutting rate of an oxypropane torch is taken from Victor Welding, Cutting and Heating Apparatus catalog, Victor Equipment Company, St. Louis, MO.

**Table 8. Comparison of DOE Test Data for the
FireJet® 1000 with an Oxypropane Torch**

	FireJet® 1000	Oxypropane
Flame Temperature (°F)	5126°F	4000°F
Flame Speed (feet per second)	5600 (Mach 1.7)	300
Fuel Cost (per hour)	\$1.60	\$6
Cutting Rate (inches per minute)	1	7

The flame temperature and velocity measured during the test are both less than claimed by the manufacturer. The reasons for this are not known; however, the test report¹⁰ cites difficulties with maintaining the proper fuel flow because of clogged fuel filters. This may account for some of the difference. Regarding cutting speed, note that the data for the oxypropane torch is with the torch operating in its normal excess oxygen mode. If extra oxygen were fed to the Model 1000 flame, significantly faster cutting would be expected.

The FireJet® 1000 has some disadvantages:

- The cutting rate with carbon steel may be less than achieved by an oxyacetylene torch. Additional testing is needed to determine cutting rates for the thin steel typical of ships.
- Water cooling and electric power must be provided to the torch. This adds complexity to the system.
- The very high operating temperature produces more infrared radiation than conventional oxyacetylene torches, increasing the risk of eye injury if a protective helmet is not worn.
- The torch is a small rocket engine. When the torch is ignited, a reaction thrust is generated. The operator must learn to anticipate and accommodate this thrust.
- Noise levels can be as high as 108 dB, requiring ear protection for the torch operator and other workers in the area.

¹⁰ DIAL Report 10575, /tr 95-4, FireJet® 1000 Test Report, August 1995.

Demineralized cooling water must be provided to the Model 1000 torch. The Russian application uses a cooling water reservoir from which water is withdrawn, circulated through the torch, and returned. During torch operation, the reservoir water gradually heats and eventually becomes so warm that it can no longer effectively cool the torch. Assuming no heat loss to ambient, the performance of a reservoir will be as shown in Table 9.

Table 9. FireJet® 1000 Cooling Water Reservoir Performance

Reservoir Capacity (Gallons)	Starting Temperature (°F)	Operating Time (hrs)
150	50	6.75
	75	5.25
	100	4
250	50	11
	75	8.75
	100	6.5

As seen from Table 9, a 250-gallon reservoir would be appropriate for a day's work aboard a ship. This is very large and cumbersome object to handle aboard ship, and therefore a smaller reservoir, cooled by an air radiator or an electrically powered cooler, may be preferable. Alternately, development of ceramic parts for the torch head materials that can withstand the high temperatures without cooling would eliminate the need for the cooling system.

The Model 1000, operating at very high temperatures, may produce gaseous waste products that are different in amount and composition than those produced by conventional oxygen-fuel or electric arc torches. Whether the differences are significant with respect to safety of the workers or release of fumes to the environment is not known.

The FireJet® system uses inexpensive and readily available fuel and may serve as a single-purpose torch for cutting all shipboard metals. Additional testing and development of the system is needed to:

- Upgrade the Model 500, optimize and measure the cutting speed of both models for the different metals encountered in ships, and compare the cutting speeds with other torch systems.
- Explore use of oxygen cutting gas with the Model 1000.

- Simplify the Model 1000 cooling system or develop ceramic parts so that the cooling system is not needed.
- Test for any significant differences, with regard to environment or worker safety, in fume production.

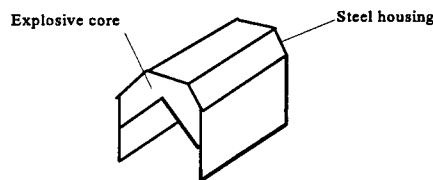
5.2.2 Explosive Cutting¹¹

The use of explosives to cut steel is a mature technology employed in mining, building demolition, and ordnance disposal. Long, narrow strips of explosives, called linear charges, are affixed to the surfaces to be cut and detonated. The explosion creates a highly compressed strip of gas along the line of the charge that acts like a knife edge that cuts through the target. Cuts are clean and can be made precisely. Very little heat is deposited in the metal surrounding the cut; therefore, there are few if any metal fumes or combustion products generated, other than from the explosion itself. Technicians trained in explosives are needed to install and ignite the materials. The key shortcomings of this technology are flying debris, the noise of the explosions, and explosive safety concerns.

Explosive cutting tape is available from a number of manufacturers in two basic forms: the linear-shaped charges and explosive cutting tape.

Linear-shaped charges are metal-encased strips of explosive with a chevron-shaped cross-section available in lengths up to 10 feet. Figure 10 provides an illustration.

Figure 10
Linear Shaped Charge



The sections can be quickly installed on the intended cut-lines with duct tape at a rate of about 100 feet every 20 minutes. The explosive core of the charge differs depending on the task. For cutting 0.5-inch mild steel plate, a loading of about 400 grains of explosive per foot is sufficient. Loadings to cut up to 3.15-inch steel are available.¹²

¹¹ Goex International Company, Inc., and the Ensign Bickford Company Inc.

¹² Courtesy of Goex International Company, Inc., Cleburn, TX.

Explosive cutting tapes are foam-encased, 20-foot adhesive-faced rolls of explosive installed by sticking the tape to the surface of the material to be cut. The installation takes about half the time of linear-shaped charges, but the lack of a precisely shaped geometry in the explosive makes it less efficient for cutting, and for this reason the tape must contain about six times the explosive (2400 grains per foot).¹³

Both types of charges are produced by several manufacturers. Charges can be customized and optimized for ship breaking to minimize installation time, to open only seams, to sever specific grades and thicknesses of metal, and to minimize the noise. Shots could be set up during a shift by explosives technicians and fired at the turn of a shift, as in the mining industry. These explosives are commonly used in mines, and some manufacturers claim that the gases created by the explosion are not hazardous. If this is true, no special ventilation would be needed following an explosion.

Were all of a Mariner C-4 or C-5 cargo ship hull to be sectioned using explosives, it is estimated that about 50,000 feet would be required. A linear-shaped charge carrying about 400 grains of explosive per foot costs about \$8 per foot in quantity. Allowing an additional \$2 per foot for installation, sufficient explosives to section one ship would cost about \$500,000. This is clearly too high to warrant routine use of this technology. However, the speed of the process (instantaneous), the absence of a fire hazard and reduced fume generation, coupled with other sectioning technology such as mobile shears, may warrant its use for special applications such as for sectioning heavy foundations.

Aside from high cost, there are other disadvantages to be addressed. With shaped charges, the metal housing is blown to small pieces by the explosion and loose material can fly about inside the cut. The use of explosives for cutting apart old ships assumes that the charges can be carefully laid out to avoid unanticipated collapses of the hull or decks following the cut. The explosive report may be unacceptable in some neighborhoods. All of these issues require attention.

Explosive cutting offers several advantages that suggest further development is warranted.

- Reduced cut-line preparation. While asbestos and other fibrous insulation material will have to be removed from the cut lines before cutting to avoid dust formation, it may be feasible to leave adhesives and paint residues in place. So little heat is deposited on the cut line that the formation of toxic partial combustion products is likely to be nil.
- Instantaneous cutting. Explosive cutting is instantaneous once the tape is set up. Conversely, the cutting of 50,000 feet of 0.5-inch steel with oxygen-fuel torches would take over 800 hours.

¹³ Courtesy of the Ensign Bickford Company, Simsbury, CT.

- **Reduced metal fume generation.** Virtually no metal fumes are generated by heating of the cut metal. The only gases released to the atmosphere are those resulting from the detonation of the explosives.

5.2.3 Laser Cutting

Lasers, reaching power densities up to 10^9 watts per square inch, can heat a target to 5,000°F or higher in a fraction of a second, which is sufficient to not only melt but even vaporize many metals.

The word “laser” is an acronym for Light Amplification by Stimulated Emission of Radiation. The first practical laser was built in 1960 from a cylindrical synthetic ruby crystal. Many types of lasers have been developed since then, including carbon dioxide lasers and neodymium-yttrium-aluminum-garnet (ND:YAG) lasers that develop enough power to melt steel.

Laser cutters use very high energy laser beams to heat and melt the areas under the beam and have been used for many years in cutting thin materials. In 1991, a U.S. Navy sponsored study was conducted by the Applied Physics Laboratory (APL) of The Pennsylvania State University to determine whether lasers could be used to cut high-strength submarine steel up to 2½ inches thick (with and without insulation coatings), electric cables, and asbestos thermal insulation.

Figures 11 and 12 illustrate the experimental setup for the tests. Note that for all tests, a fixed carbon dioxide (CO₂) laser was used with the beam directed to the materials through a system of mirrors. Table 10 summarizes some of the results of the cutting tests that were run on bare high-strength steel plates. Many other tests were run with steel plates coated with various thermal insulation and sound-quieting materials. Different cutting gases were tried. Oxygen provides for much faster cutting because of oxidation, but it tended to start a violent fire if any combustible materials were in the vicinity of the cut.

Table 10. Laser Cutting Test Results

Material	Laser Power (kW)	Cutting Speed (inches per minute)	Cutting Gas Composition	Cutting Gas Pressure (psig)
3/4-inch HY 80 Steel	12	15	Air	400
3/4-inch HY 80 Steel	12	15	Nitrogen	600
1 1/4-inch HY 80 Steel	20	60	Oxygen	500
2 1/2-inc Armored Electric Cable	20	20	Oxygen	200
Asbestos Insulation	10	15	Oxygen	100

Figure 11. Laser Cutting Chamber.

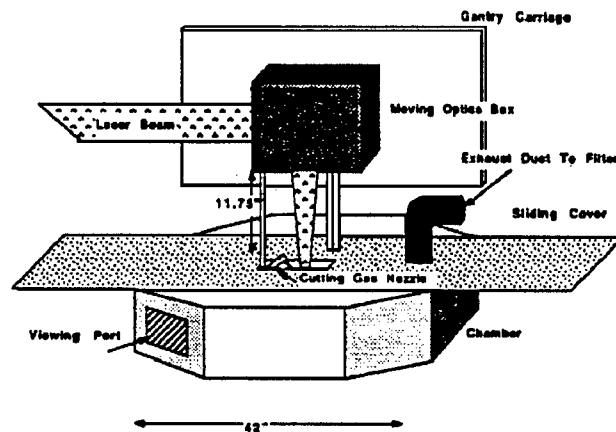
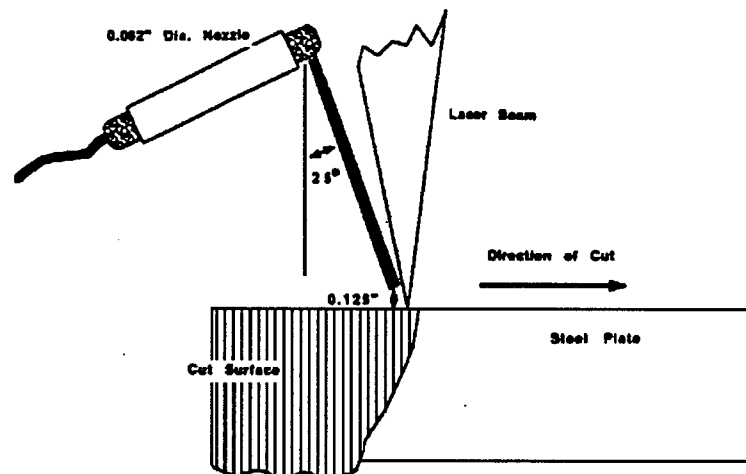


Figure 12. Laser Cutting Nozzle Configuration.



No tests were run with thin, mild steel plates typical of surface ship hull plating, but the results of the study did show that high-powered CO₂ lasers will rapidly cut thick steel plates at up to 60 inches per minute¹⁴ and therefore should cut thin steel plates even faster. The laser was also

¹⁴ Denny et al., The Pennsylvania State University Applied Physics Laboratory, *Laser Hull Cutting Program*, August 6, 1991.

shown effective in cutting armored electric cable up to 2-1/2 inches in diameter and even asbestos insulation. Tests were conducted to determine the optimum relationships among such parameters as laser power, travel speed, cutting nozzle design and orientation, and the composition and pressure of the cutting gas.

When cutting asbestos, the beam appeared to have vitrified and sealed the asbestos material. Monitoring revealed no airborne asbestos. Only one asbestos cutting test was conducted; therefore, the optimum parameters for this application have not been explored. In 1992, more Navy-sponsored tests at APL explored the cutting of steel coated with PCB-contaminated sound-dampening felt to determine if cuts could be made without significant generation of dioxins and furans (without precleaning of the cut lines) and to determine if lasers could be used to burn off PCB residues without significant generation of dioxins and furans.¹⁵

The cutting tests showed that approximately 98.2% of the PCBs in way of the cut line were destroyed by the laser but about 2000 nanograms of dioxin and furan were released to the atmosphere in the test chamber per inch of cut. EPA regulates dioxins and furans to significantly lower levels. While there are no standards specifically applicable to cutting of painted metal surfaces, the EPA limits hazardous waste incinerator emissions to no more than 0.2 nanogram of dioxins and furans per cubic meter of exhaust gas. Thus it appears that laser cutting of PCB contaminated surfaces would not be acceptable.

The cleaning tests showed that 99.98% of the organic contaminants were removed from surfaces exposed to a scanned laser beam (moved back and forth so that the entire test area is exposed to laser energy). Dioxin and furan releases were very low, about 0.05 nanogram of dioxins and furans released per square inch of surface cleaned. These values suggest that laser cleaning may be acceptable.

There are several difficulties with the adoption of this technology in the ship breaking/recycling industry. Foremost is the laser system itself. The 1991 and 1992 tests were run with a fixed CO₂ laser. The laser power was delivered to the materials to be cut through a series of eight mirrors set up in a laboratory. Mirror systems are not practical for delivery of laser power in a field situation where irregular shapes and sizes of materials are to be cut. Fiber-optic systems could work, but the wavelength of the CO₂ laser (10.6 μ m) is not suited to fiber-optic cables. Also, the wavelength of CO₂ lasers does not couple well with copper and copper alloys and aluminum (these metals reflect rather than adsorb light), so cutting is slow. ND:YAG solid state lasers, which produce light at 1.06 μ m, will overcome these problems, but existing ND:YAG lasers can deliver no more than 3kW, significantly less than CO₂ lasers, and cutting will probably be as low as 5 inches per minute, much less than existing oxygen-fuel torches. Also, ND:YAG lasers are not safe for eyes, raising concerns for personnel safety.

¹⁵ Denny et al., The Pennsylvania State University Applied Physics Laboratory, *Laser Cutting of PCB-Laden Materials*, September 30, 1993.

Equipment cost is another potential hurdle. Commercial ND:YAG/fiber optic laser cutting systems do not exist; therefore, cost estimates of eventual systems that might emerge from further development are uncertain. However, a 3kW ND:YAG laser can be purchased for about \$400,000 and fiber optic cables and a remote manipulator system (which might be needed for personnel safety) can be purchased for an additional \$100,000 to \$200,000. The total price of a complete commercial system would probably be less. Operating costs are also uncertain, but it can be said that lasers are electrically inefficient machines, converting only about 10% of the input electric energy to laser energy. Thus a 3 kW laser will require not less than 30kW of electric power. This equates to about \$2 per hour for electricity at typical East Coast electricity rates.

In conclusion, it appears that laser cutting is not yet developed to a state suitable for near-term application to ship breaking/recycling. Significant further development of ND:YAG lasers or other laser systems that are compatible with fiber optic energy delivery systems are needed before this technology is practical.

5.2.4 Water Jet Cutting

High pressure abrasive water jet cutting, sometimes called cold cutting, is used for industrial cutting where heat cannot be tolerated. It is used for removal, cutting, and shaping of explosives, and for cutting rubber, glass, stone, marble, plywood, and many other materials. According to one manufacturer, about 1400 water-jet cutting machines are in service in the United States today. Commercial systems are table-mounted systems, where the material to be cut is placed on a table beneath a fixed water jet head and is moved as desired to make the cuts.

High pressure water jet cutting is a mature and rapidly improving technology. High-pressure water (up to 55,000 psig), mixed with an abrasive selected for the material to be cut, is pumped through an orifice (ranging from 0.01 to 0.05 inch in diameter) and directed at the surface to be cut. Abrasives include garnet, sand, and copper slag. An average system will use about one half to one gallon of water and one half to one pound of abrasive per minute of operation. Ingersoll Rand, the largest domestic supplier of water jet systems, provides either diamond or sapphire orifices with their systems.¹⁶ Diamond orifices are the most expensive (\$600-\$700 each) but the most durable, lasting for up to 200 hours of steady use.

Water jet systems are used in robot-operated manufacturing lines. The footprint for a typical 45,000 psig system would be a pallet about 4 feet by 8 feet including all pumps and controls and a gantry to position the cutting head. The length of the transfer hose must be less than 100 feet to limit the water pressure loss.

¹⁶ Personal communication, W. J. Schaefer Assoc. (Marcell) and Ingersol Rand.

Cutting rates range up to 15 inches per minute (ipm) for 1/4-inch steel plate, and 6 ipm for 1/2-inch. The cutting speed is proportional to the abrasive particle size, larger being faster. Garnet is the most expensive and most universal abrasive, costing \$0.32 per pound (\$640 per ton), but it can be used only once as it breaks down.

Rough cost information was supplied by Ingersoll-Rand for a table top system to cut 0.5-inch mild steel. A capital investment of \$145,000 is required for one system with a 5-year life. Considering the cost of maintenance, replacement parts, and consumables, the operating cost of such a system will be about \$0.07 per inch of cut or about \$22 per hour (at a cutting speed of 5.3 ipm). Total cost per hour, including amortization and maintenance costs, is about \$0.26 per inch of cut, or \$85 per hour of operation.

Development is underway on lower pressure systems (less than 10,000 psig) that use smaller, lighter pumps and related equipment to supply 10 to 20 gallons per minute of water to the jet. Because of lower pressure, abrasives do not break down and can be reused up to 11 times, but the cutting rate is slower. Lower pressure systems are not yet as widely employed as high-pressure systems, but the technology is mature and ready for deployment.

Water jet systems have been explored for cutting of submarine hull steel at the Puget Sound Naval Shipyard. As predicted by the manufacturers, the systems were found to cut slowly. Also, the accumulation of water and grit in the workplace was difficult to handle. For these reasons, water jet systems cannot compete with conventional torch cutting at the present time.

The most significant advantage of the waterjet principle in a ship breaking/recycling environment is the absence of air emissions. Future tightening of air emission regulations may lead to reconsideration of water jets. Development of mobile systems to replace torches for cutting aboard ship may afford a low-cost, fume-free cutting method.

5.2.5 Cutting Technology Comparisons

A wide variety of potentially improved cutting technologies is available. Table 11 provides a quick comparison among those considered in this report.

5.3 WASTE PROCESSING TECHNOLOGY

Ship breaking/recycling produces a wide variety of hazardous and non-hazardous wastes. PCB wastes, rubber and plastic debris, asbestos, fuel and cargo sludges, paint chips, wood, fabrics, slag, waste water, and many other wastes are produced by recycling. A ship recycler processing 50,000 tons of ships per year could expect to generate up to 3,500 tons of waste, about 10 tons per day. The volume of waste water will vary with rainfall and leakage but can add up to several thousand gallons per day, requiring processing capabilities in the range of tens of gallons per minute. At the present time, ship recyclers rely largely on purchased services for disposal of

Table 11. Cutting Technology Comparisons

Technology	Cutting Rate for 0.5-inch Steel (ipm)	Cost per Foot of Cut	Development Required?	Comments
Oxyacetylene & Oxypropane	Up to 24	\$2	No	Industry standard; high air emissions
Plasma Arc	10	Low	No	Short power cord
Mobile Shears	Up to 60	Low	No	Difficult in confined space; missile hazard
FireJet®*	6 to 12	\$1-\$2	Yes	Requires optimization for ship breaking/recycling
Explosive Tape	Instantaneous	\$8	No	Noise concerns
Laser†	Over 60	High	Yes	Explore ND:YAG systems
Water Jet	6	\$1	Yes/No	Explore for specialized applications ashore

* May be useful for burning off hull residues in-situ.

† May be useful for insulation and residue removal.

these wastes. There are, however, several new waste processing technologies that could be used in-yard to destroy wastes and, in some cases, convert them to profitable products. In-yard destruction of wastes also has certain advantages regarding long-term liability for hazardous wastes, discussed in References 2 and 3. There are three broad categories of waste management technologies that could apply to ship breaking/recycling:

- Waste water processing. Rainwater, process water and harbor water leakage all make their way into the hulls during recycling, become contaminated with oily residues, metals, and chemicals from cutting operations, and must be collected and properly managed. Water processing technology is available to remove the hazardous constituents from such water and produce water of sufficient quality for release to sanitary sewers or directly to the harbor.
- Waste oxidation. This group of technologies includes incinerators and devices that operate essentially like incinerators, oxidizing solid, liquid or gaseous wastes to carbon dioxide, water and other oxides. Partial oxidation of complex organic molecules can lead to some extremely hazardous chemicals. Therefore, waste oxidation systems must incorporate features to ensure that oxidation is complete.
- Waste reduction. This group of technologies includes chemical reduction processes (the opposite of oxidation) where solid, liquid or gaseous wastes are heated to very high temperatures in the absence of oxygen to “reduce” the complex molecules of the waste to the constituent elements or very simple hydrogen containing compounds such as methane. This type of technology does not usually produce complex hazardous chemicals.

Technologies within each of these three groups are discussed in turn.

5.3.1 Waste Water Processing

Hundreds of firms market different waste water processing systems, but all operate on three fundamental principles: ion exchange, filtration, and chemical separation. Ion exchange systems are specifically designed to exchange some impurity in waste water for something better. Filtration systems range from simple beds of sand to advanced membrane filters that allow molecules of a predetermined size and less to pass through. Chemical separation systems, such as dissolved air flotation, utilize chemicals to precipitate undesirable impurities and dissolved air (foam) to float the precipitates to the top, where they are skimmed off.

Some of these technologies have found particular niches. Reverse-osmosis machines, which force water at very high pressure (above the so-called osmotic pressure) through special glass tubes where water but little else passes through the tubes, have been developed for producing fresh water from sea water. These machines use less energy and are less complex than distillation plants and are now replacing distillation plants throughout the maritime community (both military and civilian). Small, practical, inexpensive reverse osmosis units are now available for pleasure boats.

The system (or systems) of choice for any particular industrial situation depends on many factors, such as the volume of the waste, the concentration and type of impurities in the water, the local environmental rules and regulations regarding discharge of waste water, and the cost to pay somebody to simply haul the waste away. Many firms are now finding that the cost of the last option is often higher than the cost to purchase and operate modern waste processing systems. While all possible technologies cannot be covered in this paper, two that have been proven to process waste water of the kinds encountered in ship breaking/recycling, at a cost lower than purchased waste disposal services, are described below.

5.3.1.1 Dissolved Air Flotation

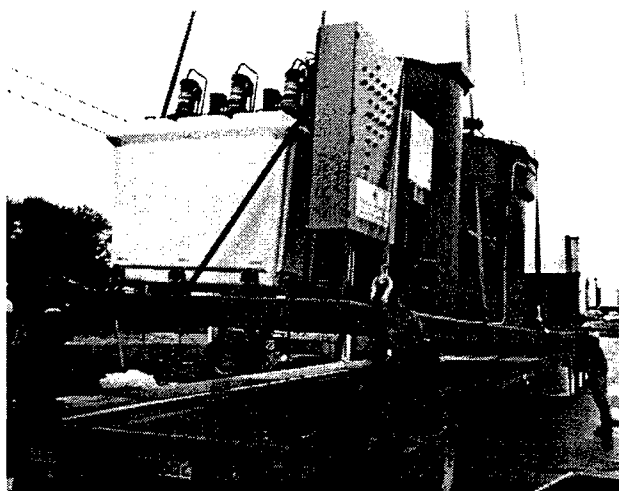
Dissolved air flotation is commonly used for processing of sewage and industrial wastes.¹⁷ The process involves the addition of chemicals to a vat of waste to precipitate and coagulate the impurities, followed by injection of fine bubbles of air (dissolved air) to float the impurities to the surface where they can be skimmed off. Systems are available from a number of manufacturers or can be assembled from parts of the user's own design. Figure 13 illustrates a 50-gallon-per-minute system from one manufacturer as it is being unloaded from a truck.¹⁸

¹⁷ Jalbert & Associates, Inc., Dissolved Air Flotation System (DAF), March, 1992.

¹⁸ Ibid.

Properly run, dissolved air flotation systems can produce water of adequate quality to be released to local sanitary sewer systems for a cost of a few cents per gallon. The purchase price of a system varies with the volume of water to be processed and the nature of the contaminants to be removed. Figure 13 depicts a system for processing 50 gallons per minute (72,000 gallons per day) of lightly contaminated bilge water at a cost of no more than \$150,000 and possibly less depending on the treatment regime required to clean the water. The cost of dissolved air systems may be less than the cost of purchased waste water disposal services, particularly if the wastes are regulated as hazardous wastes. Reference 5 cites a disposal cost for large volumes of hazardous waste of over \$0.32 per pound, or \$2.56 per gallon.

**Figure 13. Dissolved Air Flotation
Waste Water Processor**



5.3.1.2 Membrane Processing

Hydrophilic (water seeking) membranes that pass water but little else are gaining acceptance for waste processing. The Navy has used a membrane system at the Naval Weapons Station, Earle, New Jersey for several years for processing up to 1 million gallons of bilge water from ships being serviced at the weapons loading docks.¹⁹

¹⁹ *Navy Bilgewater Membrane Treatment System*, January 7, 1994.

The system operates at a waste inlet flow rate of approximately 20 gallons per minute, processing water in two stages. The first stage is a vertical parallel plate gravity oil-water separator that coalesces oil droplets in the waste as it slowly passes horizontally through closely spaced plastic plates in a tank. As they coalesce, the droplets float to the top where they are drawn off. The water, now with less oil in it, flows next to the ultrafiltration stage where it passes into a group of 16 hollow fiber polysulfone membrane bundles. Purified water passes through the walls of the membranes, and waste materials, now more concentrated, flow on within the fibers and emerge where they are collected as concentrated waste.

A duplicate system would cost approximately \$100,000 to assemble. The membranes gradually become fouled with impurities and must be replaced once each year at a cost of about \$10,000. High concentrations of some organic chemicals, such as acetone, will attack and destroy the membranes. Overall, the operating and maintenance costs average about \$0.19 per gallon of water processed. The Navy is now exploring ceramic membranes that are expected to have longer life and lower operating costs.

In conclusion, there are many different water processing systems that could successfully treat at reasonable costs much of the waste water generated during ship breaking/recycling.

5.3.2 Waste Oxidation Systems

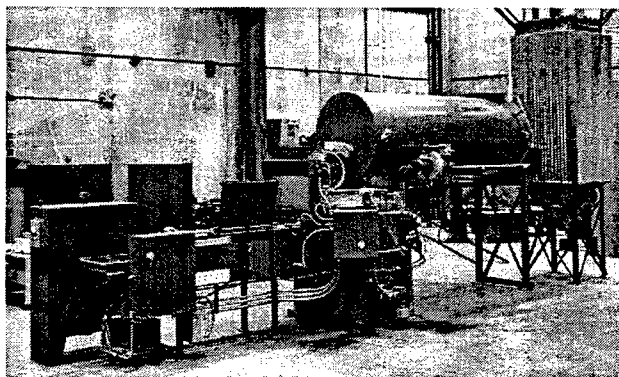
Waste oxidation is the most common waste destruction method. In concept at least, the simplest waste oxidation systems are incinerators, where combustible waste is burned in air to form oxides such as carbon dioxide. Partial or incomplete combustion is the fundamental problem with waste oxidation, which is overcome in many modern systems. Many times, the products of incomplete combustion are more noxious than the waste itself. For example, chlorine containing wastes such as polyvinyl chloride plastic, if oxidized incompletely, will form phosgene, a poison gas used in World War I. The key to successful oxidation is to ensure the complete oxidation of the waste. Three modern systems that have been engineered to do this are discussed below.

5.3.2.1 Incinerators

Advanced incineration systems will completely oxidize nearly any organic material and many inorganic materials. They achieve this by ensuring high temperatures are maintained in the waste destruction chamber(s), forcing air to the fire so that combustion is ensured, and employing secondary or even tertiary combustion stages for the gases released by the first stage. Filters and gas “scrubbing” systems remove fly ash and acids from the gaseous effluent, and handling systems collect and contain the ash. Incinerators of almost any size are available to oxidize solids, liquids and gases in almost any amounts with destruction efficiencies of

99.9999%. A small incinerator for destroying up to 1 ton per day of solid wastes is shown in Figure 14.²⁰ Similar units in a range of sizes up to 75 tons per day are available.

**Figure 14. One Ton per Day
Industrial Incinerator**



Large hazardous waste incinerators charge up to \$937 to destroy 1 ton of waste, while on-site incinerators are often less expensive, as low as \$300 per ton because of savings for transportation, provided there is sufficient waste to justify the installation.²¹

5.3.2.2 Mobile Infrared Thermal Destruction

The mobile infrared thermal destruction unit²² uses infrared lamps to heat the first of two oxidation stages. The principal advantage of the system, according to the manufacturer, is that the waste can be exposed to precisely controlled temperatures for precisely controlled times to ensure complete destruction. Figure 15 illustrates the process, which involves:

- A primary combustion chamber where wastes are heated with infrared energy.
- A secondary combustion chamber where gases released from the primary chamber are burned a second time.
- An off-gas cleanup system.

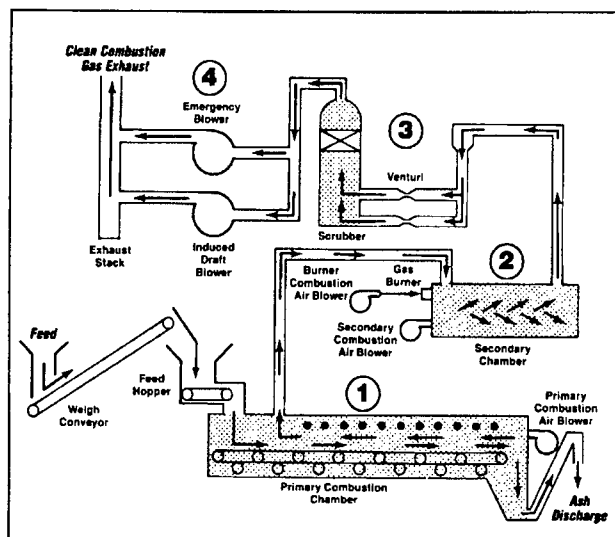
²⁰ Courtesy of Svedala Industries Inc, Danville, PA.

²¹ Courtesy of Dr. Lawrence H. Dubois, Advanced Research Projects Agency, Office of Defense Sciences, Department of Defense.

²² OHM Corporation, Mobile Infrared Thermal Destruction Unit, September 1991.

- Exhaust blowers to ensure the gas pressure in the upstream systems is always less than atmospheric.

Figure 15. Mobile Infrared Thermal Destruction Process



This system was developed for the destruction of PCBs in contaminated soils at PCB spill sites. However, it may also be useful in ship breaking/recycling, where large amounts of PCB wastes are generated.

Mobile infrared thermal destruction units are available on portable flatbed chassis. The largest, when assembled, has a footprint of about 50 feet by 200 feet, consisting of a control station, both furnaces, the gas scrubber, and other accessories. The capacity of the large unit is about 7 tons per hour. Intermittent feed is acceptable. The fixed cost of a large unit is about \$1 million, and the operating cost is about \$300 per ton of waste processed. A smaller unit having a capacity of about 3 tons per hour and an operating cost of about \$350 per ton is also available.

5.3.2.3 Supercritical Water Oxidation

When heated above its critical temperature and pressure (about 705°F and 3300 psig), water becomes a powerful solvent and oxidizer, able to host and rapidly oxidize a wide range of organic substances, producing non-hazardous by-products. A supercritical water oxidation system, operating at about 1400°F, could provide about 99% conversion of organics to carbon dioxide and water during exposures of about 100 seconds. A large number of government and

private organizations are involved in ongoing development of the technology.²³ Wastes are typically mixed at concentrations of from 1 to 20 weight percent with water, pressurized, preheated and then delivered to a reaction chamber where the temperature and time are closely controlled. Current systems have corrosion, scale and fouling problems resulting from precipitation of inorganic salts (such as sodium chloride) that are formed when caustics are injected to neutralize acidity in the reactor. The process is exothermic (heat producing), and so heat can be recovered from the reaction chamber and used for preheating of the waste. Other products such as carbon dioxide might also be recovered and sold to help defray the cost of the system. The Navy has evaluated this technology for use aboard ships to process household wastes.

Systems being demonstrated range from 800 pounds per day to 160 pounds per hour for processing of waste munitions, rocket propellants, sewage sludge and pharmaceuticals. In 1995, the Department of Defense Advanced Research Projects Agency announced a 30-month program to design, build and demonstrate a test plant occupying a footprint of 8 by 9 feet, standing 10 feet tall, and weighing about 4 tons to handle about 100 pounds per hour of solid wastes aboard Navy ships. Commercialization for processing industrial aqueous waste is being pursued.

Costs for such systems are difficult to project because they are sensitive to the type of waste and the resulting need to deal with precipitation of inorganic salts that can clog the piping. Wastes that have very low levels of acid-generating elements (such as sulfur and chlorine) will have very little precipitation and can be processed with little or no need to deal with precipitates. Wastes that are rich in acid precursors will require complex additional systems to deal with the precipitate; these can double the footprint and complexity of the machine. Even within these extremes, however, waste streams with waste concentrations of 1 to 20 percent by weight in waste are projected to cost somewhere between \$100 and \$400 per ton to process. This is equal to or significantly less than other oxidation systems, hence the interest in further development.

A commercial demonstration plant is operating at Huntsman Corporation (Texaco) for processing long-chain organics and amines in industrial waste effluents. A system optimized for these parameters may have application in processing of bilge waste from ship breaking/recycling. The technology is also being pursued for destroying plastics in municipal and medical waste and may work for destroying the nonmetallic parts of electric cables, freeing the copper for recycling.

5.3.3 Waste Reduction Systems

Waste reduction is the chemical opposite of waste oxidation. Waste reduction systems function by heating wastes in the absence of air or oxygen, and sometimes with a reducing agent such as hydrogen present, to "reduce" wastes to their constituent elements or very simple hydrogen-rich

²³ The Departments of Energy, Defense, Navy, Commerce and Army are working on supercritical water oxidation programs.

compounds. A complex waste such as rubber, consisting of complex molecules of carbon, hydrogen and oxygen, will be reduced to methane (CH_4) and water (H_2O). In the previous section, one of the problems with waste oxidation systems that was noted was that incomplete oxidation of PVC plastic can form phosgene, a poison gas. In a waste reduction system, the PVC would be reduced to methane and hydrochloric acid. Although acids are dangerous compounds, they can easily be neutralized by straightforward “scrubbing” systems.

Waste reduction systems are new developments now being advanced because of their simple, easily controlled by-products. Several new technologies are emerging on the market. Four technologies that may have application to the processing of wastes from ship breaking/recycling are described.

5.3.3.1 Plasma Arc Pyrolysis

This system employs an ultra-high-temperature electric plasma arc, operating between 12,000°F and 16,000°F, to heat a containment vessel to greater than 3,000°F where wastes are destroyed in the absence of oxygen.²⁴ The plasma arc principle is the same as the plasma arc torch described in Section 3.4.2, only this system is much larger. Systems employing both approaches (the arc is struck between the waste and an electrode or the arc is struck inside a plasma chamber, forming a plasma which is directed onto the waste) are available or under development.

Under the extreme heat of the plasma, wastes break down into elements or very simple compounds and fuel gas (carbon monoxide and hydrogen). By manipulating the environmental conditions or adding reactants, the process can be adjusted to yield the desired end products. Both organic and inorganic wastes can be processed simultaneously without pre-sorting. Because it is not necessarily an oxidation process, the volume of gaseous products can be small, allowing the overall system to be smaller than equivalent incinerators. Also, one of the products is fuel gas (carbon monoxide and hydrogen) which can be used on site or sold as an industrial fuel. One manufacturer claims that the energy recovered from fuel gas may exceed the energy input needed to form the plasma.

Several products can be recovered from the melt which collects in the reaction vessel, depending on the feedstock composition. Some metals can be tapped from the molten mass as they accumulate in layers, the heaviest on the bottom. Nonreducible metals and less desirable ones (arsenic, cadmium, etc.) can be reacted with silica to form metal silicates which, when cooled, solidify to nonleachable obsidian aggregate that is useful as construction aggregate, abrasive, or mineral wool feedstock. Volatile metals (mercury, zinc, etc) are recoverable by controlled filtration of the off-gases. Waste destruction efficiencies well above 99% are reported.

²⁴ Consolidated Defense Corporation, *The STARTECH Plasma-Electric Waste Converter*, undated.

Pilot plasma-arc thermal destruction plants are being built for mixed municipal and medical wastes demonstrations. The U.S. Navy is exploring the technology for destruction of wastes aboard ships. Shipboard units having a capacity of 500-1000 pounds per hour would occupy a footprint of about 18 by 8 feet and stand about 10 feet tall, and would require input electric power of about 530 kWh per ton of waste processed at 440 VAC. Such a system is estimated to cost about \$1 million and would require replacement of electrodes about once every 300 operating hours. The technology is modular and scalable up to about 2,000 tons per day.

Purchase and operating cost information for plasma arc systems is considered proprietary and therefore is not available at this time.

5.3.3.2 Waste Vitrification

Vitrification is a product of a high-temperature technology that involves melting to destroy inorganic materials and some combination of pyrolysis (thermal decomposition), gasification (conversion to carbon monoxide and hydrogen) and, if appropriate, oxidation.²⁵ The process is comparable to plasma arc pyrolysis; and, in one of its manifestations, it uses a plasma arc to generate heat. Wastes are heated to 3000°F by passing an electrical current through a bed of solid material (electrical resistance or I²R heating) or by passing a continuous electrical arc through the material (plasma-arc heating). Destruction efficiencies for many hazardous waste materials of 99.999% or more have been reported.

As with plasma arc systems, volatiles from organics exit the heating chamber and can be collected for recycling and/or burning, and inorganics melt and form a liquid pool layered by density in the bottom of the chamber. Molten metals can be tapped from the chamber. By adding silica reactants to the melt, hazardous inorganics can be tied up in obsidian that can be sold.

The technology is maturing rapidly. Modular plasma arc heated systems with capacities of about 2 to 5 tons per day can be purchased from several manufacturers and scaled up to many hundreds of tons per day. A 2- to 5-ton-per-day system would cost up to \$5 million and could be placed on a barge. Units up to 2.5 tons per day can be palletized for transport on a trailer. One manufacturer is designing units with capacities as large as 2,000 tons per day.

Manufacturers claim that operating costs are \$20-\$30 per ton for 100-200 tons per day units.

²⁵ Battelle Pacific Northwest Laboratory, *Vitrification of Wastes*, undated.

5.3.3.3 Molten Metal Waste Processing

This system involves a proprietary technique called the catalytic extraction process (CEP) which uses the strongly reducing environment of a molten metal bath at about 2800°F to completely dissociate waste into its constituent elements.²⁶

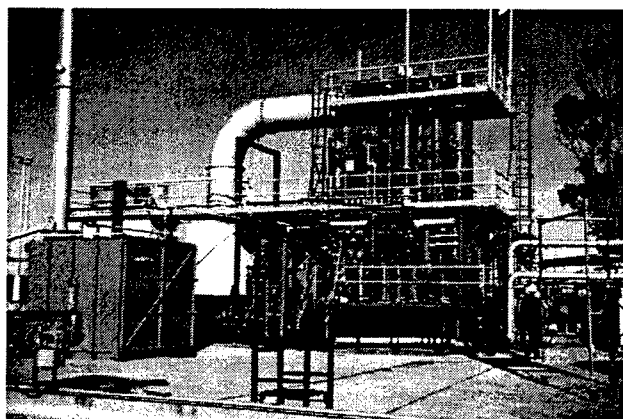
Metals released from the waste accumulate in the bath, while the resulting fuel gas is recoverable. Heat can be provided by combustion or electricity. The molten metal process handles organic and inorganic wastes and mixtures of both, and produces recoverable products such as metals and fuel gas.

The manufacturer is building two commercial-size plants of interest, one in Bay City, Texas, to process up to 65 tons per day of hazardous and non-hazardous chemical wastes for Hoechst-Celanese, and the other in Oak Ridge, Tennessee, for the Department of Energy to process mixed radioactive and hazardous waste. The installations vary in price from about \$13 million to \$24 million. Information on the systems operating cost was not available.

5.3.3.4 Hydrogen Reduction

This system is based on heating organic wastes in a hydrogen atmosphere at approximately 1600°F.²⁷ The process reduces all organic wastes to hydrogen, methane, carbon monoxide and halogen and sulfur acids. Scrubbing of off-gases is required to prevent the release of acid reaction products such as hydrogen chloride. The hydrogen, methane, and other simple organic gases can be used to heat the system and, with a steam reformer, provide much of the hydrogen needed for the reduction process. Figure 16 illustrates the system.

Figure 16. Hydrogen Reduction System



²⁶ Molten Metal Technology Inc., Waltham, MA.

²⁷ ECO LOGIC International Inc., *The ECO LOGIC Process for Destruction and Recycling of Organic Contaminants*, July 1995.

Solids are processed one batch at a time in an oven, but multiple ovens can be used to provide essentially continuous processing. The machinery can be sized to process 100 to 300 tons per day of contaminated soil or sediments and 20 to 30 tons per day of pure organic waste. In its present manifestation, the hydrogen reduction system is envisioned for use in cleaning up contaminated soil and liquids at hazardous waste sites. The system is not sold, but is moved by the manufacturer to the waste site, operated until the job is done, and moved on. The manufacturer claims that waste processing costs range from \$400 to \$1,800 per ton, depending on the organic content. The system requires an area about 200 feet on a side to set up. Destruction efficiencies exceed 99.9999%.

5.3.4 Summary and Conclusions

A number of new waste processing technologies have been discussed in this section. Table 12 provides a quick comparison.

Table 12. Waste Processing Technology Comparisons

	Technology	Unit Cost	Operating Cost	Processing Rate	Comments
Waste Water Processing	Dissolved Air Flotation	\$150,000	\$2.56/gallon of hazardous waste	50 gpm	Existing technology
	Membrane Processing	\$100,000	\$0.19/gallon	20 gpm	Existing technology
Waste Oxidation	Incinerators	N/A	\$300 to \$900/ton	up to 75 tons/day	Existing technology
	Infrared Thermal Destruction	\$1,000,000	\$300/ton	7 tons/hour	Existing technology
	Supercritical Water Oxidation	N/A	up to \$400/hour	up to 160 lbs/hour	Developmental
Waste Reduction	Plasma Arc Pyrolysis	N/A	N/A	N/A	New technology; commercially available
	Waste Vitrification	\$5,000,000	\$30/ton	65 tons/day	New technology; commercially available
	Molten Metal Waste Processing	\$13 -24 million	N/A	65 tons/day	New technology; commercially available
	Hydrogen Reduction	none*	up to \$1800/ton	30 tons/day	New technology; commercially available

* Vendor provides equipment on site.

N/A - Not available

The technologies described above illustrate most of the fundamental principles of waste processing systems that are commercially available or are in advanced stages of development. Hundreds of competing systems are offered by dozens of manufacturers, however, each having its own advantages. Waste processing, particularly hazardous waste processing, is becoming increasingly specialized, with each particular system being tailored to fit the exact nature of the wastes and the local environment, both physical and regulatory. The system or systems that best suit a ship breaking/recycling firm, and for that matter whether on-site waste processing is advantageous at all, depend on these variables.

The cost of waste disposal, using current capabilities, will establish the economic viability of the alternatives. Reference 5 notes that the approximate cost to dispose of solid PCB-bearing wastes in the Norfolk, Virginia area averages about \$0.69 per pound. In a recycling operation processing 50,000 tons of ships per year, about 3,500 tons of waste can be expected. If 10% of this waste contains PCBs, the disposal cost will amount to over \$500,000 per year. Alternatives must be able to compete with this figure, and several appear in range. A careful economic and regulatory analysis of candidate technology, fitted to the ship breaking/recycling waste stream, is needed.

5.4 INDUSTRIAL PLANNING TECHNOLOGY

Computer-based aids have been used for many years to help manage industrial processes, improve product quality, optimize schedules, shorten lead times, and lower cost. Computer aids range from simple accounting systems to detailed models ("virtual" models) that incorporate mathematical models of every aspect of a manufacturing, sale and distribution process.

Virtual manufacturing involves construction of a computer-based mathematical model of an entire manufacturing environment, containing interactive elements representing costs, prices, productivity, markets, production data and so forth. The models allow changes in the environment to be tested mathematically and the process optimized before any actual changes are put in place. Such models can be used for new manufacturing initiatives so that the results can be predicted and the process optimized before the manufacturing work begins, and for existing processes so that the dynamics involved can be better understood and optimized.

Virtual manufacturing is finding successful applications across a growing number of industries. Many universities, industries, and government laboratories are involved in applying it to many fields, including manufacturing jet engines and airplanes, producing beer, and scheduling communications. The Oak Ridge National Laboratory, the Applied Research Laboratory at The Pennsylvania State University, and other research facilities have active research programs in this area.^{28, 29} Applied to the ship breaking/recycling process, virtual manufacturing could be used to design an optimum recycling facility, consolidate buyer information and mill requirements, keep

²⁸ Oak Ridge National Laboratory, *Centers for Manufacturing Technology, Highlights and Accomplishments Through FY 1994*, May 16, 1994.

²⁹ Presentation to W. J. Schafer Assoc. (Marcell) by The Pennsylvania State University, *Applied Research Laboratory* (H. Watson), undated.

track of market prices and requirements, and assist in matching the products of each salvage step with the “best” market price. Workload scheduling and sharing of tools (cranes, cutters, etc.) can also be optimized to lower costs.

The Puget Sound Naval Shipyard has had significant success with improved planning.³⁰ While not yet employing the virtual manufacturing concept, the yard is adopting modern information management technology to carefully plan each step in the process and optimize the use of existing facilities. They constantly evaluate and, where appropriate, bring in new equipment and processes that can add to productivity. They plan each recycling job to ensure that the unique demands of each can be accommodated and surprises minimized, if not eliminated.

The result of this effort is a decrease in the cost of recycling ballistic missile submarines by nearly 14% over the past year and a half, with further reductions anticipated. Many innovations have been implemented. The yard has instituted project management, where recycling of a ship is viewed as a single task to be expedited by a project team. Planning and estimating tools, detailed breakdowns of each step in the recycling process (called Work Breakdown Structures), and other such information tools are used. Several improved technologies have been evaluated and adopted. For example:

- Drydock crane lifts are planned to maximize the value of each lift and coordinate the subsequent movements of materials through the shipyard with available and newly purchased portable lifting equipment.
- Recyclable products are better tailored to fit market needs; e.g., large pieces of lead, imbedded in ship’s structure, are sold as a unit to recyclers that are equipped to melt out the lead, saving the expense of this work at the yard.
- Ergonomic improvements in tool design are being sought to reduce injuries and improve worker efficiency. The use of conveyors to speed the movement of materials from the docks to laydown areas is being explored.
- Improved blasting techniques and systems, discussed in Section 3.2, have been developed and deployed.

Virtual manufacturing technology and improved planning at all levels are resulting in improvements in many industries. Both approaches have applicability to commercial ship breaking/recycling and might, if tested, reveal new, profitable approaches.

³⁰ Personal communication, MSCL Inc. (MacKinnon) and Naval Sea Systems Command (Orr) , October 1995.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Difficulties face the domestic ship breaking/recycling industry. Strong overseas competition for hulls, complex and growing domestic environment, safety, and health rules, and a volatile scrap market create a difficult business environment. Few domestic ship recyclers remain in business. The recent discovery of widespread PCB materials in old Navy and MARAD ships has caused the EPA to prohibit their continued export for recycling, leaving the ship owners in a difficult position. Other environmental problems, such as asbestos and lead paint, add further to the domestic burdens, and, as noted in Reference 2, foreign countries are becoming more cautious about importing hazards. As inventories of old ships grow and fill the available space, the government will have to resolve the problem. The options include remediating environment, health, and safety problems before the ships are exported or taking steps to restore the domestic recycling industry.

In this report, the current and advanced technologies and processes are reviewed to determine whether there are new approaches that might help resolve these problems. Some technologies, such as laser cutting, do not appear to be ready, while others, such as large shears, have already been adopted to some extent and await only a careful planned application to optimize their use.

From this report emerges a notional idea of a fully modern ship breaking/recycling facility.

- Deep-water slips that can handle large ships and that are fitted with bulwarks that allow large mobile shears and cranes to approach closely and cut directly on the hulls;
- Very large boxing shears that are fed 30-ton sections of hull and structure at one time and that cut steel to the proper market size with no manual labor;
- Conveyors or lifts that move the metal from the shears directly to gondola cars for immediate shipment;
- Nearby laydown areas to accumulate, sort, and compact specialty metals such as aluminum and reusable parts;
- Shredders and separators for separating metals from nonmetals with minimum labor;
- Modern hand-held cutting tools able to quickly cut any metal or structure the mobile shears cannot reach;
- Waste processing facilities to handle the water and solid wastes on site and produce useful products;
- Integrated market planning to ensure the best price for the products; and, most importantly,

- A single set of environmental rules and regulations that put forth a cohesive and effective environmental control, monitoring, and reporting scheme.

The precise technologies that could make this notion real have yet to be selected and proven in a working system. To do that, it is recommended that a demonstration project be established to test the merits of all potentially applicable technologies. Those that prove successful could be made available for private exploitation to restore the domestic ship breaking/recycling industry and other recycling industries, feed valuable metals and other materials to other industrial sectors, and resolve difficult environmental problems at home instead of exporting them to foreign nations.

REFERENCES

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2. Maritime Administration, Report MA-ENV-820-96003-B, *Substantive Law on Environmentally Compliant Ship Breaking/Recycling in the United States*, July 1997.
3. Maritime Administration, Report MA-ENV-820-96003-A, *The Legal Environment for Environmentally Compliant Ship Breaking/Recycling in the United States*, July 1997.
4. Maritime Administration, Report MA-ENV-820-96003-D, *Sampling and Analysis*, Report, July 1997.
5. Maritime Administration, Report MA-ENV-820-96003-E, *Survey of Ships and Materials*, July 1997.
6. Maritime Administration, Report MA-ENV-820-96003-F, *The Markets, Cost and Benefits of Ship Breaking/Recycling in the United States*, July 1997.
7. Maritime Administration, Report MA-ENV-820-96003, *Environmental Assessment, Environmental Assessment of the Sale of National Defense Reserve Fleet Vessels for Scrapping*, July 1997.
8. U.S. Naval Nuclear Powered Submarine Inactivation, Disposal, and Recycling, March 1995.

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APPENDIX 1

INFORMATION SOURCES

Following is a list of the companies and contacts from which much of the information in this report was acquired. In some cases, personal contacts by MSCL Inc. personnel were made. In others, information was gained from available literature. This list is provided only to guide the readers who require more information.

Category	Company	Phone	Comments
Cleaning Technology	Safe Systems Inc. P.O. Box 309 Kent, WA 98035	(206)251-8662	Grit blast equipment
Cleaning Technology	Virginia Materials P.O. Box 7400 Norfolk, VA 23509	(804)855-0155	Grit blasting
Cutting Technology	Allied Gator Inc. 2100 Poland Avenue Youngstown, OH 44502	(216)744-0808	Shears
Cutting Technology	American Carbide Saw Company 238 Tanner Avenue Hatboro, PA 19040	(800)537-2371	Metal cutting saws
Cutting Technology	Applied Research Laboratory P. E. Denney The Pennsylvania State University P.O. Box 30 State College, PA 16804	(814)865-3031	Laser cutting and cleaning
Cutting Technology	Counselor Equipment Company P.O. Box 428 Hudson, OH 44326	(800)783-6567	Shears, shredders and other metal processing equipment
Cutting Technology	D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (NIIEFA) 1, Sovetsk PR., Metallostroy St. Petersburg 189631 Russia	(812)265-5761	Laser cutting
Cutting Technology	FireJet Corporation 565 Fifth Avenue New York, NY 10017	(212)687-2900	Oxy-kerosene torch
Cutting Technology	FireJet Systems 7200 Trapers Place Springfield, VA 22153	(703)451-6466	Oxy-kerosene torch
Cutting Technology	Goex International Company, Inc. Cleburn, TX 76031	(817)641-2261	Explosive cutting
Cutting Technology	Harris Waste Management Group 200 Clover Reach Road Peachtree City, GA 30260	(800)373-9131	Shears
Cutting Technology	Ingersoll-Rand P.O. Box 231 635 West 12th Street Baxter Springs, KS 66713-0231	(316)856-2151	Waterjet cutting manufacturing
Cutting Technology	Ingersoll-Rand 23629 Industrial Park Drive Farmington Hills, MI 48335	(810)471-0888	Waterjet cutting sales

Category	Company	Phone	Comments
Cutting Technology	Lindemann Recycling Equipment 10620 Southern Loop Blvd. Pineville, NC 28134	(704)587-9646	Shears
Cutting Technology	National Liquid Blasters 29830 Beck Road Wixom, MI 48393	(810)624-5555	Waterjet cutting, low pressure technology
Cutting Technology	Northeast Science and Technology Dr. James P. Reilly 117 North Shore Blvd. East Sandwich, MA 02537	(508)833-8980	Laser cutting
Cutting Technology	Texas Shredder Inc. 14607 San Pedro, Suite 215 San Antonio, TX 78232	(210)491-9521	Shredders
Cutting Technology	The Ensign-Bickford Company Simsbury, CT 06070	(203)843-2464	Explosive cutting
Cutting Technology	Universal Engineering 800 First Avenue NW Cedar Rapids, IA 52405-3999	(319)365-0441	Shredders
Cutting Technology	University of Missouri Rock Mechanics Facility 1006 Kings Highway Rolla, MO 65401	(314)341-4311	Waterjet cutting
Cutting Technology	US Jetting Inc. 850 McFarland Road Alpharetta, GA 30201	(770)740-9917	Waterjet cutting, low pressure technology
Cutting Technology	Veratech Attachments 61 County Line Road Somerville, NJ 08876	(908)218-8907	Shears
Cutting Technology	Victor Equipment Company 101 S. Hanley Road St. Louis, MO 63105	(314)721-5573	Cutting torches
Cutting Technology	Vladimir V. Khukharev, Yuri V. Efremov and Gennady A. Baranov NULAZE 93A Obvodny Canal Embankment Suite 5/2 St Petersburg 191126 Russia	(812)210-1838	Laser cutting
Electric Cable Recycling	H.E.L.P.E.R. Inc. P.O. Box 505 Madison, SD 57042	(605)256-6254	Has EPA permit for recycling of electric cables containing PCBs
Metals Recycling	Commercial Metals Corp. P.O. Box 1046 Dallas, TX 75221	(214)689-4339	Not presently active in ship breaking/recycling
Metals Recycling	Jacobsen Metal Company P.O. Box 7596 Chesapeake, VA 23324	(804)543-2066	Not presently active in ship breaking/recycling

Category	Company	Phone	Comments
Metals Recycling	North American Marine Salvage P.O. Box 146 Bordentown, NJ 08505	(610)647-7475	Not presently active in ship breaking/recycling
Metals Recycling	Northwest Demolition 25440 S.W. Newland Road Wilsonville, OR 97070	(503)638-6900	Not presently active in ship breaking/recycling
Metals Recycling	Schnitzer Group 3200 Yeon Avenue Portland, OR 97210	(503)224-9900	Not presently active in ship breaking/recycling
Metals Recycling	Tacoma Metal Processors 1919 Portland Avenue Tacoma, WA 98421	(206)627-1440	Brokers scrap from Puget Sound Naval Shipyard
Metals Recycling	TCI Inc. RD 3 P.O. Box 153T Falls Road Industrial Park Hudson, NY 12534	(518)828-9997	Not presently active in ship breaking/recycling
Navy PCB Program	Westinghouse Electric Corporation Machinery Technology Division 2341 Jefferson Davis Highway, Suite 1010 Arlington, VA 22202	(703)418-1430	Technical support of Navy shipboard PCB program
Planning Technology	Applied Research Laboratory The Pennsylvania State University Manufacturing Technology Department C. H. Brickell, Jr. P.O. Box 30 State College, PA 16804-0030	(814)863-9900	Virtual manufacturing
Ship Breaking/Recycling	KERSAND Corp. 3000 Childs Street Baltimore, MD 21226	(410)354-1644	Business relationship with Seawitch Salvage
Ship Breaking/Recycling	Puget Sound Naval Shipyard Bremerton, WA 98314-5000	(360)476-3161	Nuclear powered submarine and surface ship breaking/recycling
Ship Breaking/Recycling	Rig Ventures 6665 East 14th Street Brownsville, TX 78520	(210)831-4531	Does not operate breaking facility. Purchases ships for breaking elsewhere
Ship Breaking/Recycling	Seawitch Salvage 3000 Childs Street Baltimore, MD 21226	(410)354-1644	Active in ship breaking/recycling
Ship Breaking/Recycling	Wilmington Resources Inc. 2200 U.S. Highway 421 North Wilmington, NC 28410	(910)762-5252	Active in ship breaking/recycling
Ship Storage	Maritime Administration James River Reserve Fleet Fort Eustis, VA 23604	(804)887-3233	Storage of MARAD inactive ships reserved for future use or awaiting disposition

Category	Company	Phone	Comments
Ship Storage	Naval Inactive Ship Maintenance Facility 2450 Wycoff Way Bremerton, WA 98314-5250	(360)476-3510	Storage of Navy inactive ships reserved for future use or awaiting disposition
Waste Processing	Aerojet General Corp P.O. Box 13222 Sacramento, CA 95813	(916)351-8618	Supercritical water oxidation
Waste Processing	Air Pollution Control Products, Inc. P.O. Box 6113 Ashland, VA 23005	(804)550-2842	Incineration
Waste Processing	Battelle Pacific Northwest Laboratory Richland, WA 99352	(509)372-4161	Plasma arc destruction
Waste Processing	Consolidated Defense 79 Old Ridgefield Road Wilton, CT 06897	(203)762-2499	Plasma arc destruction
Waste Processing	ECO LOGIC International Inc. 2385 Huron Parkway Ann Arbor, MI 48104	(313)973-2780	Hydrogen reduction
Waste Processing	Foster Wheeler International 1701 Pennsylvania Ave NW Washington, DC 20006 Research Department: Livingston, NJ	(202)298-7750 (201)535-2309	Supercritical water oxidation
Waste Processing	General Atomics 1100 17th St NW Washington, DC 20036	(202)496-8200	Supercritical water oxidation
Waste Processing	Jalbert & Associates Inc 150 South Main Street Norfolk, VA 25525	(804)545-5555	Dissolved air flotation
Waste Processing	Molten Metal Technology Inc. 51 Sawyer Road Waltham, MA 02154	(617)487-7622	Catalytic extraction
Waste Processing	Naval Sea Systems Command Naval Surface Warfare Center Carderock Division Annapolis Detachment Annapolis, MD 21402-5067	(410)293-2773	Membrane processing
Waste Processing	OHM Corp 16406 US Route 224 East Findlay, OH 45840	(800)537-9540	I-R Thermal destruction
Waste Processing	Plasma Energy Applied Technology 260 Finney Drive Huntsville, AL 35824	(205)464-7001	Plasma arc destruction
Waste Processing	Process Combustion Corporation P.O. Box 12866 Pittsburgh, PA 15241	(412)655-0955	Incinerators

Category	Company	Phone	Comments
Waste Processing	Process Combustion Corporation P.O. Box 12866 Pittsburgh, PA 15241	(412)655-0955	Incineration
Waste Processing	Sandia National Laboratory P.O. Box 5800 Albuquerque, NM 87185	(505)845-0011	Supercritical water oxidation
Waste Processing	Svedala Pyro Systems Division Kennedy Van Saun 350 Railroad Street Danville, PA 17821	(717)275-3050	Incineration

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